THE ATMOSPHERIC NITROGEN INDUSTRY

WITH SPECIAL CONSIDERATION OF THE PRODUCTION OF AMMONIA AND NITRIC ACID

BY

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WITH 72 ILLUSTRATIONS

VOL. I.

LONDON

J & A. CHURCHILL

7 GREAT MARLBOROUGH STREET

1923

Printed in Great Britain

AUTHOR'S PREFACE

When, on November 30th, 1913, Professor Ferdinand Fischer, of Bad Homburg, requested me to write a volume on the atmospheric nitrogen industry for his series of works on chemical technology, no one realised what was to happen during the next few years. The Great War occurred and the young industry developed greatly under its influence. This development is reflected in the size of the present volume, which greatly exceeded that which was anticipated. It was often very difficult to collect the material, and I must appeal to the indulgence of my readers, as the most conflicting figures and other data are to be found in the German and foreign literature. In general, I was able to deal with the literature up to the middle of March, 1921.

It is my pleasant duty to thank the editor of this series, Professor Binz, of Berlin, and the publisher, Otto Spamer, of Leipzig, for the trouble and expense which they have devoted to this work. Several important authorities and firms have assisted me in the most friendly fashion. Amongst these I may mention with an expression of gratitude, the Bayrischen Stickstoffwerke (more particularly, Professor N. Caro and Dr. Siebner, both of Berlin), Gesellschaft für Lindes Eismaschinen, A.G., Abtlg. Gas-Verflüssigung, of Höllriegelskreuth near Munich, Berlin-Anhaltische Maschinenbau, A.G., of Berlin, Firma A. Borsig, of Berlin-Tegel, Fr. Krupp, A.G., of Essen, Norgesalpeter-Verkaufs, G.m.b.H., of Berlin, Gesellschaft für Kraftübertragung of Berlin, Lonza-Werke, Elektrochemische Fabriken, G.m.b.H., of Waldshut (Baden), Tonwerk Biebrich, A.G., of Biebrich-on-Rhine, Amag-Hilpert Pegnitzhütte, of Nürnberg, Steuler & Co., G.m.b.H., of Coblenz, Firma Heinr. Koppers of Essen-on-Ruhr, Herren Dr. O. Schönherr, of Dresden, Professor Dr. F. Häusser, of Dortmund-Eving, Professor Dr. Kaiser, of Tutzing, Dr. E. Brauer, of Miltitz (Bez. Leipzig), Professor J. Moscicki, of Cracow, Mr. Harry Pauling, of Berlin, Mr. Siegfr. Barth, of Düsseldorf-Oberkassel, and a number of other leading firms and authorities who do not wish to be mentioned for business reasons.

An attempt has been made to make this volume a standard work; consequently a large number of economic data have been incorporated which may be of interest to later workers; for the same reason a detailed survey of the literature has been given.

DR. BRUNO WAESER.

TRANSLATOR'S PREFACE

As no English work of similar magnitude existed dealing with the fixation of atmospheric nitrogen, it was thought by the translator that an English edition of Waeser's book would be useful to that section of the public which has an interest in the subject but a limited knowledge of the German language.

The field covered by Dr. Waeser is very wide and quite apart from the purely technological aspect of the industry, the book affords illuminating sidelights on conditions and tendencies in Germany before, during, and after the Great War.

Considerable developments have occurred since the original volume was written, and these are dealt with in the Foreword which Dr. J. F. Crowley has kindly contributed.

ERNEST FYLEMAN.

SUTTON, SURREY.

FOREWORD

In September, 1898, Sir William Crookes delivered an epoch-making address before the members of the British Association at Bristol. Though he averred later that it had not been his intention to create a sensation, his words—the seriously considered words of a scientist of world-wide repute—may be said to have caused a "cosmic scare." To summarise the address in his own words :

> "I stated that under present conditions of heedless culture, a scarcity of wheat is within appreciable distance ; that wheat-growing land all over the world is becoming exhausted, and that at some future time - in my opinion not far distant - no available wheat land will be left. But I also pointed out that Nature's resources, properly utilised, are ample. I urged that, instead of being satisfied with an average yield of 12·7 bushels per acre, a moderate dressing of chemical manure would pull up the average to 20 bushels—thus postponing the day of dearth to so distant a period that we and our sons and grandsons may legitimately live without undue solicitude for the future."

The chemical manure to which Sir William Crookes referred was nitrogenous manure. It has been stated by Sir E. J. Russell that an average of experiments extending over sixty-one years at Rothamsted showed a yield of 12·6 bushels of wheat per acre from unmanured land, that the addition of phosphates and potash without nitrogenous manure increased the yield to 14·5 bushels, that is, by 15 per cent., that with 43 lbs. of nitrogen per acre in addition to potash and phosphates the yield increased to 23·2 bushels per acre, that is, by 85 per cent., and with 129 lbs. of nitrogen per acre to 36·6 bushels, or by nearly 200 per cent.

The average annual yield per acre in 1898 in different countries, according to Crookes, was :—

Denmark	41·8	bushels per acre.
United Kingdom	29·1	,, ,,
United States	12	,, ,,
South Australia	7	,, ,,

The fact that the bulk of the world supplies of wheat came from the United States was responsible for the world average of 12·7 bushels per acre referred to by Crookes. The higher yield in

European countries was largely due to the use of inorganic manure, and in this connection it is interesting to note that to increase the average world yield of wheat to 20 bushels per acre, the yield Crookes considered desirable, there would be required, on the basis of the yield given by Russell and the acreage under wheat to-day, 3,180,000 tons of nitrogen per annum, or approximately two-and-a-half times the quantity available at the present time.

If, then, the mere application of a dressing of chemical manure would provide the yield considered necessary by Crookes, from what did his alarm, and that of his hearers and world-wide readers, arise? It arose from the simple fact that at the time at which he spoke there was no known source from which the necessary chemical manure could be obtained. The only considerable sources of fixed nitrogen were sodium nitrate, the natural product of the Chilean beds, and ammonium sulphate, obtained as a by-product in the destructive distillation of coal. Laboratory experiments had shown various methods by which the vast quantity of nitrogen which exists in the air might be fixed, but the industry, based on the fixation of atmospheric nitrogen which is the subject of Dr. Waeser's present work, was merely a matter of conjecture among speculative scientists.

On this question we may again quote Crookes :—

> "For years past attempts have been made to effect the fixation of atmospheric nitrogen, and some of the processes have met with sufficient partial success to warrant experimentalists in pushing their trials still further, but I think I am right in saying that no process has yet been brought to the notice of scientific or commercial men which can be considered successful, either as regards cost or yield of products. The fixation of atmospheric nitrogen, therefore, is one of the great discoveries awaiting the ingenuity of chemists. It is certainly deeply important in its practical bearings on the future welfare and happiness of the civilised races of mankind" . . . and . . . "unless we can class it among certainties to come the great Caucasian race will cease to be foremost in the world, and will be squeezed out of existence by races to whom wheaten bread is not the staff of life."

Certain considerations arise directly from the foregoing. For example, how far have the prophecies of Crookes been fulfilled, and how would the food supply of the civilised world stand to-day if no new source of inorganic fertiliser had been discovered in the interval? Further, what have the chemists of the world succeeded in doing as regards the production of nitrogenous fertilisers to justify the trust that Crookes reposed in them? The first and second points I propose

to consider now, the third forms the subject-matter of Dr. Waeser's book.

Crookes estimated the bread-eating population of the world to be 516,500,000, and deduced from statistics that it would increase in a geometrical ratio. On this basis he arrived at an estimate of the bread-eating population of the world for each year up to 1941. He made the assumption, apparently, that the use of wheaten bread would continue to be confined to Europe, North and South America, and Australia ; in other words, to what he described as the "white" population of the world, and, except for this assumption, it can be said that he made a fairly accurate forecast of the world's bread-eating population. In the interval, however, growing sections of the inhabitants of eastern countries, such as China and Japan, the numbers of which cannot be estimated, had become bread eaters, and for this reason the bread-eating population of the world is greater than that forecasted by Crookes. Crookes estimated the average annual consumption of wheat by the bread-eating population to be 4·5 bushels per head. If we assume the consumption of wheat to be still confined to the "white" population the total would correspond to an average of slightly over 5 bushels per head, and, owing, no doubt, to the unforeseen consumption by non-white people, the aggregate of the world's demand for wheat is some 11 per cent. greater than that anticipated by Crookes.

Other relevant figures are the number of acres under wheat and the average yield per acre. Crookes estimated the number of acres under wheat in 1898 to be 183,000,000 acres and the average yield per acre to be 12·7 bushels. He considered that if all the wheat-growing countries increased to the utmost the area under cultivation, an addition of 100,000,000 acres only could be made, giving a total of 283,000,000 acres, which, at an average yield of 12·7 bushels per acre, would suffice in his opinion, to feed the world until 1931, but not much longer. For the years 1909 to 1913 the average area under cultivation was 266,000,000 acres and the average yield 13·9 bushels per acre. In other words almost the whole of the land regarded by Crookes as possible wheat-growing land had been placed under cultivation, but the output per acre had been increased by 10 per cent. only. It is not possible to give complete statistics for more recent years owing to the fact that the figures for Russia are not available.

We may, therefore, summarise the position as follows:—The total consumption of wheat has become greater than that anticipated by Crookes because of the addition, not contemplated

by him, of new consumers in the Far East and elsewhere. The number of acres under cultivation is not far short of the total which he estimated to be possible, and which he calculated would feed the world only until 1931, while the yield per acre has increased by 10 per cent. only.

It should be pointed out that the area on the earth's surface on which wheat can be grown is limited to a certain definite climatic range, determined by extremes of temperature and of moisture in the soil. This area, has, however, been steadily extended owing to the selective breeding of wheat which has had the effect of increasing its resistance to extremes of temperature, drought, excessive moisture and plant diseases. For example, the wheat belt in Canada has been considerably extended in a northerly direction. We may assume that apart from the benefits due to selective breeding, the main increase in annual production is now to be looked for in the direction of increased productivity of the soil, which can only be secured by the increased employment of fertilisers, primarily nitrogenous fertilisers. Nitrogen is an essential constituent of all vegetation, and we have seen that the world's production of food depends in a large measure upon its application to the soil in such a form that it can be assimilated by plants, and suited to the particular conditions of soil and climate.

We now have to consider how far there will be available the enormous quantity of fixed nitrogen which will be required to meet the rapidly growing demand for nitrogen for fertilisers and for other purposes, such as the manufacture of explosives, dyestuffs and drugs. In 1898 the nitrogen content of the Chile nitrate exported was 200,000 tons; in 1925 it had increased to 370,000 tons, which may be taken as a normal output for the last fifteen years. This output is apparently incapable of serious further increase, and, moreover, it has to be recognised that the beds will one day be exhausted. Nevertheless, Chile nitrate, which was once almost the sole source of fixed nitrogen, supplied more nitrogen than all other sources until 1915, when, for the first time and owing to war conditions, it fell from its proud position. In 1916 and 1917 it regained the supremacy; in 1918 it had once more lost it, probably for ever. In 1922, an exceptional year of course, it supplied only one-fifth of the world's needs for nitrogen, and in 1925 a little under one-third.

The output of by-product ammonium sulphate corresponded in 1898 to some 90,000 tons of fixed nitrogen, and by 1913 this figure had increased to 280,000 tons. Since then the rate of production has varied but little, and at the present time shows no marked

tendency to increase. These two sources clearly then cannot meet the seriously growing need for fixed nitrogen.

Crookes had said: "Starvation may be averted through the laboratory . . . the chemist will step in and postpone the day of famine."

The problem of the fixation of atmospheric nitrogen to which Crookes referred was solved in the interval, and to such effect that from zero in 1900 the annual output from the atmospheric nitrogen industry had grown by 1925 to the impressive total of 550,000 tons, or nearly one-half of the world's production of fixed nitrogen.

The new industry is rapidly increasing in importance throughout the world, and its scope is almost unlimited. As mentioned above, the present output of Chile nitre probably represents the maximum that the nitrate fields are likely to yield even with improved methods, and accordingly the inevitable increase in the world's demand for nitrogenous fertilisers can be met only by the expansion of the fixation industry.

The fixation processes employed on a commercial scale include :—

The arc process.

The cyanamide process.

The direct synthesis of ammonia.

Regarding the arc process, the first to be established on a commercial scale, it is generally agreed that as it entails a large consumption of electrical energy there is not likely to be a substantial extension of it in any country outside Scandinavia, to which territory, where water power is exceptionally cheap, it is, indeed, at present, almost entirely confined. Moreover, the range of products obtainable by its use is practically confined to nitric acid and nitrates.

The modified arc process using enriched air, which was developed by the Nitrum A.G. in Switzerland, does not represent a sufficiently great improvement on the old arc process to justify its extension at the present time. Dr. Waeser, in his reference to this process, does not distinguish between the Nitrum A.G., Zürich, and the Nitrumwerke A.G. The former, founded in 1915, is identical with the Soc. Anon. Nitrum, and merely the owner of patents, while the latter was a subsidiary working under licence. The Nitrumwerke A.G. did not rebuild its plant at Bodio after the explosion in 1921, and is now in liquidation. A plant is still operating under the same patents at Rhina, in Baden, and belongs to the Electro Nitrum A.G., another licensee company of the Nitrum A.G. The Nitrum A.G. owns patents for the production of nitrous gases by the arc process, and also patents for the absorption of nitrogen oxides produced by the arc and the ammonia oxidation processes.

The cyanamide process is a German process, which in 1906 was established in Italy where cheap power was available, and has been considerably developed by the American Cyanamid Company and others. In this process calcium carbide, which is produced in the electric furnace, is crushed and subjected to a stream of pure nitrogen under suitable conditions. The process requires considerably less power per ton of nitrogen than the arc process, but can be successfully established only where the raw materials, namely, limestone and coke, or anthracite, are abundant and cheap.

Cyanamide has been found to be a useful fertiliser for particular soils, but under some conditions it has a considerable toxic effect. The demand for it is, therefore, somewhat limited, and its production has remained practically stationary since 1917. Cyanamide manufacturers found that in order to maintain their markets they had to convert the product into ammonia and other nitrogen compounds, and there has been in consequence a tendency among European manufacturers to replace their cyanamide plant by plant for the direct synthesis of ammonia.

Reference to Fig. A, which shows the development of the various processes for the fixation of atmospheric nitrogen from 1905, when the first plant was established, to the present day, indicates quite clearly that there has been practically no development during the last ten years in the arc or the cyanamide process. There has been, on the other hand, more particularly since 1915, a very great development in processes for the direct synthesis of ammonia. This development was largely stimulated by war conditions, particularly in Germany, as that country was unable to import Chile nitrate or ammonium sulphate in any quantity during the war period.

The first process for the direct synthesis of ammonia to be operated successfully was the Haber process of the Badische Company. The first plant was installed at Oppau in 1913, after many years of intensive effort by a large staff of research chemists and engineers, and was followed by a second plant at Merseburg. The annual capacity of Oppau is 100,000 tons of fixed nitrogen and of Merseburg 200,000 tons.

During the war the Allies were faced with a very serious problem in connection with the provision of fixed nitrogen for explosives and fertilisers, and considerable scientific activity resulted in England, France, America and Italy. It may be said, however, that during the period of the war, in the absence of anything like complete information regarding the design and technique of the Haber process, which was at that time the only synthetic ammonia process, no serious progress was made.

Billingham is at present 15,000 tons, which is to be increased to 45,000 tons and later to 60,000 tons annually.

Considerable difficulty was experienced during the first two years in getting the plant at Billingham into successful operation, but the initial difficulties have been overcome and the plant is now operating with considerable success.

In France, during the war, Georges Claude conducted a series of experiments and, subsequently, evolved a new process for the synthesis of ammonia in which high pressures of approximately 1,000 atmospheres are employed. Because of these high pressures the Claude units are much smaller than the corresponding Haber units, and, in some respects, simpler. Technical difficulties, however, arose in the manufacture and design of certain parts of the plant. Very special steels were required for the catalyst bombs, and it may be noted that the investigation and production of these steels was carried out in this country by British metallurgists. Difficulties were also experienced in connection with the compressors, but these appear to have been overcome.

The Soc. l'Air Liquide is prominently identified with the Claude process and we may mention that its capital is now considerably larger than the figure given by Dr. Waeser, being 50 million francs. Some of the plants so far installed on the Claude system utilise hydrogen obtained by the fractionation of coke-oven gas, while others use hydrogen similarly produced from water gas or by electrolysis.

In France there are plants operating at the Bethune mines, at Aniche and at La Grande Paroisse, and two other smaller plants, the total rated capacity within that country, according to information supplied to us, being about 13,000 tons of nitrogen annually. Other plants are stated to be in operation in Belgium, Spain, Italy and Japan with a total rated capacity, outside France, of about 11,000 tons annually, and we are informed that further installations are projected or in course of construction in Italy, Poland, Czecho-Slovakia and the United States.

Another process for the synthesis of ammonia was developed in Italy by Giacomo Fauser. Fauser employs a pressure of 250 atmospheres, and he informs us that plants utilising his process are in operation at Novara Sedico Bribano and Merano, with annual capacities of 3,400, 750 and 18,000 tons of ammonia respectively. Two further similar plants are projected at Firso, Sardinia and at Catrone, with annual capacities of 3,400 and 10,800 tons of ammonia respectively.

The most outstanding development of recent years, however, is

that of the Casale synthetic ammonia process. Dr. Luigi Casale, who was a lecturer in the University of Turin, resigned his teaching appointments during the war in order to devote himself wholly to research in the field of nitrogen fixation. His researches were started about 1916, and in 1920 he produced ammonia in the laboratory for the first time. Almost immediately afterwards a semi-technical plant was set up at Terni for the continuous production of some 100 tons of ammonia annually. A plant of about 300 tons' capacity was then installed, and was followed in 1923 by two plants of 1,000 and 2,700 tons' capacity respectively.

In the autumn of 1922 the writer's colleague, the late Dr. J. A. Harker, F.R.S., was asked to conduct the first professional investigation and to report on the Casale process. After this investigation he cabled :—

> "The process differs in details greatly from existing processes, is simpler and less costly to instal."

The development of this process during the last three years has been extraordinarily rapid as will be clear when it is pointed out that there are now some eighteen plants operating in eight countries, with an installed capacity of some 75,000 tons of fixed nitrogen per annum, and additional plant on order of a capacity of some 125,000 tons, or a total when completed of over 200,000 tons of fixed nitrogen per annum. Allowing for stand-by units the plants operating this process will, on completion, be capable of producing annually about 150,000 tons of fixed nitrogen, or almost one-third of the total quantity of atmospheric nitrogen fixed in 1925. This is certainly a very remarkable commercial development. The Casale process operates at about 800 atm. pressure in a closed circuit. The synthesis tube is constructed so as to secure efficient heat interchange, and the pressure container itself never attains a temperature higher than 200° C. This low temperature enables special steels to be dispensed with in the design of the catalyst bomb. The bomb has a high mechanical resistance and is not affected by the hydrogen. One of the most important features of the process is the deliberate retention of a certain percentage of ammonia in the nitrogen-hydrogen mixture to avoid all danger of overheating the catalytic mass. A portion only of the ammonia is removed from the gas issuing from the synthesis tube and the uncombined gases are made to pass repeatedly over the catalyst.

The process has been adopted by the French Government for their new national factory at Toulouse which, when completed, will have an installed capacity of some 65,000 tons of fixed nitrogen per annum. It has also recently been adopted by the Russian Govern-

ment for two plants. The high working pressures of this and the Claude process enable plants to be employed of much smaller size than would be necessary with a Haber plant for the same output. In the case of the Casale plants the technical difficulties in connection with the manufacture and operation of compressors working at the high pressures required have been overcome, and the plants are extremely simple to operate.

While the translation of Dr. Waeser's work was proceeding, a few particulars were published in Germany of a new process of ammonia synthesis, namely, the Mont Cenis process. This process is owned by the Mont Cenis Gewerkschaft and is stated to operate at a pressure of 100 to 150 atmospheres, and to employ a particularly active catalyst and a low temperature of about 400° C. The process appears to be based on patents of F. Uhde, the principal British applications being Nos. 3565 and 3566, dated February 8th, 1926, and entitled "An Improved Method of Synthetically Producing Ammonia." The first deals principally with improvements in the catalyst which enable particularly low temperatures to be employed, and the second application deals with the purification of the incoming gases. The process has not, so far, been put into commercial operation on a large scale, but we understand that a plant is projected for Northern Germany.

The synthesis of ammonia entails in the first place the preparation of pure hydrogen and nitrogen which are then mixed in the proportion of three to one and passed under pressure over a heated catalyst. The process depends mainly for its successful operation on the cost at which hydrogen can be produced. Prior to the war the whole of the hydrogen needed was produced from coal. During the war it was realised, particularly in Italy, that in countries in which there was no coal, but which possessed large water-power resources, a process was required which would utilise electric power for the production of hydrogen. As a consequence, the production of hydrogen by the electrolysis of water was developed by Casale and by Fauser for use with their synthetic plants. A number of electrolytic cells have been designed and operate quite satisfactorily, one of the more widely used being of British design and manufacture.

Where electrolytic hydrogen is employed and the nitrogen produced by burning hydrogen in air, the power required is approximately 5,000 K.W. continuous for each 7½ tons of anhydrous ammonia produced daily. By far the larger part of this power is required for the generation of hydrogen and the remainder for operating the compressors, pumps, fans and other small plant.

The Liljenroth process is a process for the simultaneous production of phosphoric acid and of hydrogen, commercial installations of which are now being erected in the United States and in Germany in association with synthetic ammonia plants. The capacity of the projected German plant is some 100 tons of P_2O_5 daily. According to this process, phosphate rock is reduced with coke in an electric furnace, with production of carbon monoxide and of phosphorus vapour. The latter is condensed and collected under water instead of being directly mixed with air and burnt to phosphorus pentoxide as is the usual practice. The phosphorus is treated with excess of steam yielding directly phosphoric acid and hydrogen. The steam is raised by burning under boilers the carbon monoxide obtained in the electric furnace. The total power requirements of the process are 1·25 h.p. years per ton of P_2O_5 obtained in the form of acid.

The by-product hydrogen, which is sufficiently pure for use in the synthesis of ammonia, is obtained in sufficient quantity to produce over 50 per cent. more ammonia than would be required to convert the phosphoric acid obtained into the usual monoammonium salt.

The Liljenroth process is an interesting example of the interlocking of chemical processes which is an important feature of modern chemical technology. It serves simultaneously to produce the necessary hydrogen and an acid of valuable fertilising properties, which is used to convert a portion of the resultant ammonia into ammonium phosphate, a substance in very considerable demand as a fertiliser as it supplies to the soil not only nitrogen, but also phosphoric acid in soluble form.

Prior to the war the only synthetic ammonia plant in operation was the Haber plant of the Badische Company at Oppau, the hydrogen being obtained from coal or from lignite. The Haber process, particularly in view of the technical difficulties of operation, is not suitable for small units, and it is doubtful if the process would be a commercial success with plant capacities much lower than, say, 20,000 tons of nitrogen per annum. It may be recalled here that when the members of the British and French Commission attached to the Allied Control Commission visited Oppau during 1919 they were told by the German chemists that even if they could erect plant identical with that at Oppau or Merseburg, they certainly could not operate it "for lack of the highly trained workers, who were absolutely essential to successful operation."

The principal feature of the newer processes is the simplicity of

the plant employed and the ease of operation. In Dr. Harker's report on the Casale process, to which reference has already been made, he stated :—

> "One of the things which struck me most about the working of the Terni plant, which had then been only two days in operation, was that none of the individuals concerned appeared to regard the operations they were conducting as anything out of the common."

On a visit to an important synthetic ammonia plant paid some twelve months ago, the writer found that the whole plant was being operated under the direct supervision of the engineer responsible for the running of the power station, and that no chemists were employed. This was a plant in which the hydrogen was produced electrolytically, and the ammonia converted directly into sulphate. It would almost appear as if the chemists had solved the nitrogen problem so successfully as to render unnecessary the employment of members of their own profession.

Another important feature of the recent developments is that economical operation can be secured with very small plants. Plants capable of producing 5 tons of anhydrous ammonia daily are in successful commercial operation in various parts of the world. Two results follow directly from the simplicity of operation, and the small size of unit that can be commercially employed. Firstly, individual small plants can be installed near the centre of consumption in each country, and secondly, by-product hydrogen from the electrolysis of brine or other sources, which hitherto went to waste, can be employed for the production of synthetic ammonia, as can also hydrogen from coke-oven gas. Every ton of pig iron produced requires about 1 ton of metallurgical coke. Every ton of coal which is coked provides about 0·7 ton of coke, and a total of some 11,000 cubic feet of stripped gas, of which approximately 5,000 cubic feet are available. This gas contains about 48 per cent. of hydrogen, of which it may be assumed that nearly 90 per cent. can be recovered by the liquefication of the other constituents. In this way approximately 3,200 cubic feet of hydrogen can be recovered per ton of pig iron produced, and this hydrogen would be sufficient for the production of 0·033 ton of fixed nitrogen. If we take the British production of pig iron at the 1924 figure of 7,319,000 tons, the fixed nitrogen that could be produced from this source would amount to some 240,000 tons. The installation of synthetic ammonia plants for the utilisation of coke-oven gas is becoming an important feature of coke-oven economy in France, and will probably be extended to other countries also.

The world position as regards the provision of inorganic nitrogen may be reviewed as follows :—

Reference to Fig. B shows that beyond any question the atmospheric nitrogen industry is taking the lead in the provision of fixed nitrogen. The output of Chile nitrate does not show any tendency to increase, and the increase in the output of by-product ammonia is unimportant compared with the total increased demand for fixed nitrogen. Reference to Fig. A shows that synthetic ammonia is now the chief product of the atmospheric nitrogen industry, that the output of calcium nitrate by the arc process is practically stationary, and that the output of cyanamide is decreasing. The following extracts from official documents issued by the United States Government in May and June, 1924, are of interest :—

> "It appears . . . that a very substantial expansion (of the nitrogen industry) is to be expected during the next five to ten years. This expansion will unquestionably be in the direction of the direct synthetic ammonia process."
>
> "There is a general concensus of opinion in this country that the direct synthetic ammonia scheme for nitrogen fixation offers greater promise of cheap nitrogen than any other process at present."

The great simplicity of the latest synthetic units has led to the installation of synthetic ammonia plants in most of the consuming countries and, indeed, in many of these countries to the installation of a number of individual plants at several centres. The policy, so far followed by the Badische Company, of concentrating manufacture in large factories with a view to supplying the world market, and of withholding licences for their processes for the production of hydrogen and of synthetic ammonia is not, in the light of recent developments, likely to continue with success. The reduction in freight charges resulting from a wide distribution of plants is a considerable economic advantage and such plants occasionally have further advantages in local conditions. There is the further very important point that distributed plants provide an insurance against a dearth of fixed nitrogen during war. Many important countries have made it part of their peace policy to develop the fixed nitrogen industry even to the extent in some cases of providing large subsidies for this purpose. In this connection it may be interesting to quote from some recent remarks by Dr. G. C. Clayton, M.P. :—

> "In this country we were fortunate in having a Navy which could keep control of the seas and which, therefore, enabled us to carry on the war with nitre from Chile, coupled with ammonia

from gasworks and gas producers. But we were very hard pressed. We had to get from Norway large quantities of calcium nitrate to convert into ammonium nitrate for amatol. In view of those dangers, it was decided that for the future we must have our own sources of synthetic ammonia. We have at Billingham a Haber plant working satisfactorily, but it is only one plant, and the fact that it is only one may be a great danger in case of air raids. We cannot depend solely on one plant. . . . Wider distribution would greatly minimise the risk from air raids."

The wider distribution referred to by Dr. Clayton as desirable from strategic considerations has only been rendered possible by the development of processes such as that of Casale which permit of the manufacture of small units, which, because of their simplicity and ease of operation, can be run with sufficient economy to compete with the large units hitherto essential.

The fixation of nitrogen, whether by the arc, cyanamide, or synthetic ammonia process, is generally only a first stage in the production of a marketable product. Nitric acid, the product of the arc process, is ordinarily converted into calcium nitrate, or into ammonium nitrate by interaction with ammonia. Much of the cyanamide which is manufactured is converted into ammonia by digestion with a dilute alkaline solution in high-pressure autoclaves, the ammonia in turn being converted into sulphate or phosphate, or oxidised to nitric acid and converted into nitrates. Urea, which is likely to become a particularly important fertiliser because of its high nitrogen content, is also produced from commercial cyanamide. The latter is converted into free cyanamide by the action of carbonic acid or other acids, and the solution so obtained is transformed into urea by the action of a dilute mineral acid. Ammonia is converted into ammonium sulphate by interaction with sulphuric acid, or latterly, and on an increasing scale, by the gypsum process, which is in use in Germany and in this country. It is also converted into ammonium nitrate, ammonium sulpho-nitrate, ammonium chloride, ammonium phosphate, and other salts. There has been a remarkable development during the last few years in the conversion of ammonia into urea. Ammonium carbamate is first produced by the interaction of ammonia and carbon dioxide, and it is then transformed into urea by heating in autoclaves at 160° C. and about 60 atmospheres pressure. This process is being carried out by the Badische Company and a new process has also been developed by Dr. Casale, which is expected to be commercially operated in the near future.

It is interesting to note that successful experiments have recently been conducted with a view to still further increasing the wheat yield produced by the application of a given quantity of fixed nitrogen.

In conclusion it may be said that the problems connected with the actual synthesis of ammonia have been solved, and but little development of a fundamental character may be looked for in this direction in future. Very considerable developments are, however, already taking place which are directed to the production of cheap hydrogen, and it may be anticipated that these developments will play an important part in the economics of the ammonia industry for some considerable time.

It is difficult to exaggerate the importance of the atmospheric nitrogen industry to any country, and it is particularly important to these islands, which import some 75 per cent. of the wheat which they consume, and in which, therefore, it is eminently desirable that the internal wheat production should be increased as far as possible.

It seems to the writer unfortunate that in this country, in financial circles, there is some lack of appreciation of the economic importance of technical developments in general, and more particularly, of those of a chemical character, such as are described in Dr. Waeser's book.

Happily, the general increase of scientific knowledge is gradually leading to some improvement in this respect, and it may, therefore, be hoped that those who still regard ammonia as primarily of importance as an adjunct to domestic cleaning and to the toilet will realise that nitrogen production is a national economic problem of the greatest importance to the future welfare of the British Empire, and indeed to the world as a whole.

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INTRODUCTION

CHAPTER I

The Historical Developments of the Nitrogen Industry prior to the Realisation of the Direct Fixation of Nitrogen

As is well known, attempts to exploit the valuable constituents of the air technically are quite modern; they were, however, preceded by a period of several centuries of scientific investigation of the properties of the air by Torricelli (1643), Otto von Guericke (about 1650), Lavoisier (1772), and many others. Such investigations succeeded thousands of years during which human beings, in common with the whole organic world, drew the fundamental bases of their existence from the atmosphere without investigating, or being able to investigate, the phenomena which they experienced and saw.

It is only proper that we should first devote a few words to the early stages of the history of saltpetre and of nitric acid. An active demand for saltpetre arose from the circumstance that it was necessary for the manufacture of black gunpowder. Potash saltpetre has been known since the earliest times; it was a main ingredient of Greek fire, the preparation of which was preserved in Byzantium as a State secret, and which was successfully used by Kallinikos (A.D. 673) and by Leo the Isaurian (A.D. 730). Little of historical value remains of the legend of the Freiburg monk, Berthold Schwarz (about 1300), beyond the fact that the use of gunpowder became more extensively known in Europe at about that period. German gunsmiths took a further step by utilising the powder to hurl shots from small arms and cannons, which latter are known to have existed in 1313. The rapid development in the use of gunpowder made the search for new methods of preparation of saltpetre imperative. In this way the industrial career of this

material, which has played and still plays such an intensive part in the cultural history of mankind, may be said to have begun.

In warm regions with light rainfall, where nitrogenous refuse rots on soil containing potash, white crusts of salt form on the surface of the soil when rains are followed by long periods of drought. Soil saltpetre, or "China salt," was obtained by collecting these deposits (sal petræ), extracting them and evaporating the extracts. Only a small accident was required, such as, for example, the observation of the deflagration caused by throwing a piece of glowing wood on to the nitrate-bearing soil, to cause the discovery of the properties of mixtures similar to Greek fire, the original home of which may probably be found in India, China or Egypt. It was these countries which supplied the first saltpetre. Ceylon and India, which are to-day the only serious exporters of natural potash saltpetre, were then already the most important. The main sources were the Ganges mud, containing about 8 per cent. of potassium nitrate and 4 per cent. of calcium nitrate, and the nitrate-bearing soil from homesteads.

We meet with saltpetre at an early date in alchemistic writings, in which it is referred to as "sal petræ," "sal petrosum," or "sal nitri" (Pseudo-Gebir, Raymund Lullus). The development of fire-arms caused the demand to increase, and saltpetre was thus the foundation of the development of chemical activity. In the fourteenth century it was well known, as was also nitric acid prepared from it by distillation of a definite mixture of saltpetre, copper sulphate and alum, the acid being known as "aqua dissolutiva" or "aqua fortis." George Agricola (1494–1555) gives a detailed description in his main work "De re Metallica," of the refining of saltpetre which had already been practised technically. The process of saltpetre production in nature was imitated by heaping up soil, animal refuse, wood ashes, lime, building waste, etc., moistened repeatedly with stable manure or urine, and then allowed to stand. When after months or years the heap was ripe the thick layers of efflorescent saltpetre were scraped off. The efflorescent "wall saltpetre" from the walls of stables which were frequently sodden with stable manure was also utilised. "Gay" saltpetre was similarly produced in the *pustas* of Hungary, and in Switzerland stable manure was utilised in "saltpetre trenches." These extremely ancient methods of production are still used in villages far removed from civilisation. In the eighteenth century their systematic exploitation was commenced. Saltpetre plantations, *salpetrières* or *nitrières* were founded, especially in France, where they were administered by a State department, and played an important part, especially at the time of the Continental blockade under the

first Napoleon. This is the first instance of that relationship between blockade and nitrogen industry which was so extraordinarily marked a feature of the Great War of 1914–18. Fairly considerable quantities of wall saltpetre were obtained in Silesia as far back as the time of Frederick the Great. This material and the crude saltpetre from the saltpetre plantations were leached in saltpetre factories. The solutions, which contained calcium nitrate, were precipitated with wood ashes (potassium carbonate) and boiled down to form crude potassium nitrate, which was then refined in the powder works to produce pure nitre.

The discovery of the nitrate deposits of Chile, and the attempts to exploit them by Thos. Haenke in 1809, form a turning point in the history of saltpetre. The earthy caliche of the almost rainless desert territory of Atacama, Antofagasta, and Tarapacá has been formed by the decomposition of vegetable and animal matter under the influence of nitrate-forming bacteria in a similar manner to that which we have already described as occurring in the nitre plantations. We now know that we may consider both processes to be accompanied by the fixation of atmospheric nitrogen, which is utilised for the synthesis of albumen by the vital activity of low forms of bacterial life. So long as the technical use of nitrates was essentially confined to the production of gunpowder, activities were restricted to the conversion of Chile saltpetre into potash saltpetre (conversion saltpetre), or "artificial East Indian saltpetre," with the help of wood ashes or, after 1863, of potassium chloride (by Vorster and Grüneberg, at Stassfurt).

The teaching of Justus von Liebig on mineral plant fertilisers (1840) was of far-reaching importance, and caused a rapid rise in the production of the Chilean nitrate field since the sixties of last century. The predominance of sodium nitrate in the world's economics began with this peaceful phase. The importance of potassium nitrate subsequently declined according to the extent to which the old black powder was replaced by smokeless organic explosives and by ammonium nitrate. Simultaneously the utilisation of nitric acid and of nitrites increased in consequence of the development of the organic heavy chemical industry, which, as is well known started its development at the same period.

At about the turn of the century, serious considerations arose as to what would happen when the Chilean deposits, which are of course limited, were exhausted. The very basis of existence of the human race was threatened; in order to avoid the disappearance of intensive agriculture and the consequent slow death by hunger of a portion, at least, of civilised mankind, or a throttling of chemical industry at

the height of its development, it was necessary to provide against the prospective future exhaustion of Chile. During this fateful period, the atmospheric nitrogen industry came into existence. It is a characteristic of the cultural history of mankind that really great discoveries are scarcely ever associated with the name of any one man, but result from a series of important new observations of which the keystone only needs to be added when the time is ripe. This idea has been expressed very finely by Max Eyth ("Zur Philosophie des Erfindens"). We realise its truth in connection with the discovery of fire, the greatest achievement of all ages, and we also realise it when considering the atmospheric nitrogen industry; we meet it again continually during the solution of the power problem, the endeavour to liberate ourselves from the dominance of coal.

In 1878, G. Meyer discovered calcium cyanamide, which we now know as the essential constituent of nitro-lime. Whereas Moissan, in 1894, was unable to combine nitrogen with pure calcium carbide even at 1,200° C., A. Frank and N. Caro succeeded in showing a year later that nitrogen could be absorbed in the form of cyanide if alkalies, salts or other materials were mixed with the calcium carbide. As their efforts were directed to the production of cyanide, Frank and Caro worked with barium carbide. In the case of both calcium and barium carbides, the addition of potash, and so forth, had a favourable effect, as under such conditions the primary nitrogen compound which was formed, and the true character of which was not yet recognised, was converted into cyanide. The calcium cyanamide industry, which has been operated industrially since 1905, is based on these experiments.

The first process of direct oxidation, or combustion of atmospheric nitrogen to nitric acid by way of nitric oxide—namely, that of Birkeland and Eyde (1903)—makes use for this purpose of the old observation of Cavendish in 1781, that the action of the electric spark on the nitrogen and oxygen of the air produces nitrogen oxides. The discovery of the catalytic oxidation of ammonia in presence of platinum is also of comparatively early date; Ostwald commenced his first technical experiments in this direction in 1901.

Aluminium nitride was first described by Briegleb and Geuther in 1862. O. Serpek introduced this substance into the large-scale technology of nitrogen. The first plant to operate his process was erected in 1909. About 1903–4, F. Haber and his co-workers commenced to study the direct synthesis of ammonia from its elements, their work being based on earlier experiments by Regnault, Berthelot, and others.

The oldest known ammonium salt is the chloride (sal ammoniac). The expressions "sal nitri" for saltpetre, and "sal ammoniac" for ammonium chloride, have both undergone a change of meaning, for "sal nitri" or "sal nitrum" originally denoted fixed alkali, and was changed in the sixteenth century into "natron" (German for soda; compare our symbol Na), whilst the old name "nitrum" has remained associated with saltpetre; in antiquity, "sal ammoniac" undoubtedly referred to ordinary rock salt from the oasis of Ammon. In the fourteenth century "sal armeniacum," "armoniacum" or "ammoniacum" was already the equivalent for ammonium chloride. The remedy "nuschadir," of the Arabian physicians of the ninth century (*nischador* in modern Serbian), was no other than our modern ammonium chloride. The term "spirit of ammonia" was coined by Bergmann in 1782, long after the material itself was known. Ammonia gas was first produced by Priestley (1733–1804). Ammonium carbonate was well known to the alchemists of the thirteenth century as "volatile lye salt" (*Spiritus urinæ*).

The lighting gas industry (Minkeles, Murdock, etc., 1784–92), ran gas liquor to waste for a long period, and only commenced producing ammonia from it about sixty years ago.

The Coke Oven Industry.—In 1675 coal was first distilled for the production of tar, and in 1735 coke was first used in blast furnaces. The coking industry has only recovered by-products for about thirty years, as the demand for such materials only arose with the development of the fertiliser and organic heavy chemical industries. The manufacture of ammonia from the raw materials of the alchemist, bones and urine, which were for centuries the only available sources, is now very unimportant compared with that from the nitrogen of coal; both groups of processes ultimately depend upon the same source, namely, atmospheric nitrogen, which became fixed at a definite stage in its ceaseless transformations—in one case in prehistoric coal and in the other case in animal products. The similar utilisation of the nitrogen of oil shale and of peat is of later date.

With regard to the preparation of the cyanogen compounds, Prussian blue has been known since 1704 (Dippel and Diesbach), prussic acid since 1782 (Scheele), and cyanogen itself since the classical investigations of Gay-Lussac in 1815. The synthesis of cyanide from atmospheric nitrogen, with which the calcium cyanamide industry is closely connected, was first attempted by L. Thompson in 1839.

If, finally, we remember the part which ammonium nitrite formed by atmospheric discharges may have played in early geological times in the first development of organic life, that Pseudo-

Gebir showed in the fourteenth century that saltpetre could be obtained by neutralising nitric acid with potash, the discovery of nitrous acid by Scheele in 1768, the recognition of the composition of nitric acid in 1784–86 by Priestley and Lavoisier, the liquefaction of air by Cailletet and Pictet in 1877, and its technical realisation by C. von Linde in 1895, we may reconstruct what may be described as the historical outline of the development of the nitrogen industry, the technical "genealogical tree" of which is indicated in Fig. 1.

Were we to describe in detail the development of the nitrate

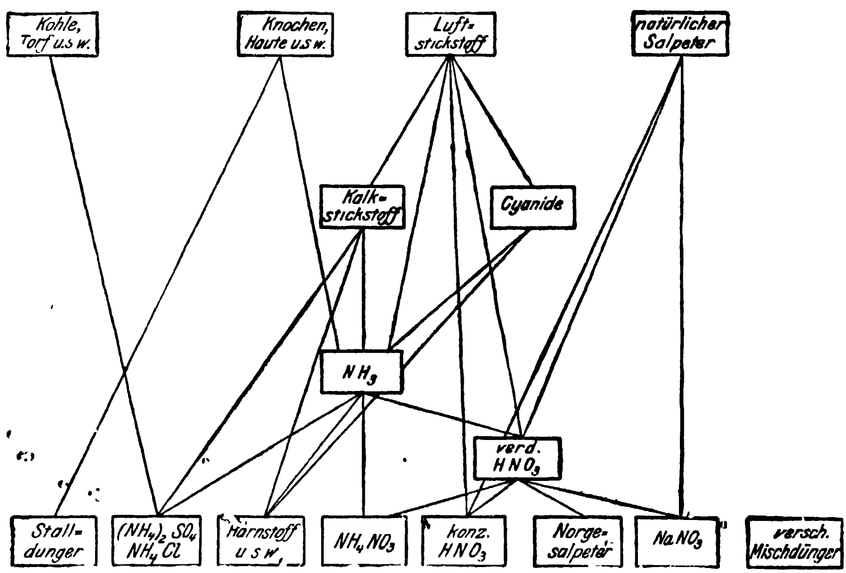

FIG. 1.

Kohle, Torf u.s.w. — Coal, peat, etc.
Knochen, Haute u.s.w. = Bones, skins, etc.
Luftstickstoff = Atmospheric nitrogen.
Natürlicher Salpeter = Natural nitrate.
Kalkstickstoff — Calcium cyanamide.
Stalldunger — Stable manure.
Harnstoff u.s.w. — Urea, etc.
Norge salpeter — Calcium nitrate (synthetic).
Verd HNO_3 — Dilute HNO_3.
Versch. Mischdunger — Various mixed fertilisers.

industry, we would have to write a considerable chapter in the cultural history of mankind. We have seen that the first industrial production of saltpetre takes us back to the nursery of technical chemistry. We also know that the fixation of atmospheric nitrogen represents a great achievement of inorganic chemistry, which had held a somewhat subordinate position at the turn of the century in comparison with organic chemistry, which for many centuries had considered the field of chemical synthesis peculiarly its own. This has been followed by a surprising development of the technology of the inorganic heavy chemical industry. As a glance at the genea-

logical tree will show, the favoured product of the synthetic process is ammonia. Atmospheric nitrogen, which was first isolated by Scheele about the year 1770, is the mother substance of the nitrogen, not only of Chile nitrate, but also of coal and of animated Nature. Decomposition processes or explosions release fresh elementary nitrogen, in the latter case with simultaneous liberation of the equivalent amount of energy in the course of a minimal time. This energy is necessary in order to attach the elements to one another. In both cases the nitrogen is restored to the atmosphere, the nitrogenous contents of which remain approximately constant. Involved in these processes we may find a particle of that pure poetry and of that hidden beauty of technology which is described to us by Max Eyth in his "Poesie und Technik."

Before considering in detail the development of the synthesis in individual countries, we will give a short account of the most important events of the Chilean nitrate industry, which is still of the greatest economic importance, and is, moreover, the school in which knowledge of the application of the products of the atmospheric nitrogen industry was gained.

"Das Sammelbuch des Vitalis de Furno und Seine Bedeutung für die Geschichte der Chemie" ("The Compendium of Vitalis de Furno and its Importance in the History of Chemistry"), by E. O. von Lippmann (*Chem. Ztg.*, 1922, pp. 25, 50, 55), contains notes on the early knowledge of saltpetre and of nitric acid in Italy, about the year 1150.

CHAPTER II

The Chilean Nitrate Industry

CHILE nitrate is sodium nitrate, $NaNO_3$. It is mainly found on the west coast of South America, more particularly between 19° and 24° south latitude, in Chile, near the boundary of Peru. The most important districts for the production of nitrate are those of Antofagasta, Tarapacá, Atacama, Tocopilla, Aguas Blancas and Taltal. The deposits are from 100 to 200 km. long and 3 to 5 km. in width. The nitrate was probably formed from decaying organic matter by bacterial action, in a soil rich in sodium chloride and lime, and was later washed into larger deposits in the desert, which has no outflow. It was here protected in its secondary beds by a cover of material impermeable to water and thus prevented from being redissolved by rainfalls, which were in any case very rare. The oxidation and nitrification processes must have been extraordinarily intensive, as iodate and perchlorate were also formed. Ostwald therefore assumes that ozone also played a part in the process. It is possible that electrical phenomena also played a part. Other nitrate deposits in California (Death Valley, San Bernardino) Colombia, Persia, Transcaspia (Schof-Kala), etc., have not hitherto been exploited on a large scale. They are much smaller than those of Chile, Peru, and Bolivia.

At the commencement of this century the life of these deposits was estimated to be about thirty to thirty-five years, and a solution of the nitrate problem consequently appeared to be a very urgent matter. In the light of present knowledge, their life is supposed to be 100 to 150 years, on the assumption of A. Bertrand that the annual increase of consumption will be about 50,000 tons; it would be 300 years on the supposition that the average production of the years 1914–19 were maintained.

The surface of the nitrate deposits usually consists of a layer of sand containing gypsum know as "chuca," embedded in which there are white fragments of anhydrite resembling pottery in appearance, and known as "loza"; below this there is a rocky conglomerate of clay, grit, fragments of felspar, porphyry and greenstone, which are cemented together by calcium, potassium, sodium and magnesium sulphates, together with a little sodium chloride,

to form a mass known as "costra." Below the costra there is a further layer in which sulphates, sodium chloride and magnesium chloride predominate; as the surface of this layer resembles a frozen, gritty gravel containing water, it is known as "congelo" (that is, "that which is frozen together"); this layer contains a small percentage of sodium nitrate. Finely grained deposits of congelo are also known as "banco."

Chuca, costra and congelo form layers 0·5 to 0·3 m. thick. Below these lies the caliche, which is 0·5 to 2 m. thick and constitutes the true crude nitrate, the best qualities of which contain 40 to 50 per cent. of $NaNO_3$, the medium qualities 30 to 40 per cent. and the qualities of less value 17 to 30 per cent. In exceptionally favourable circumstances there may be as much as 75 per cent. $NaNO_3$. The general composition is as follows (according to K. A. Hofmann):—

50	per cent.	$NaNO_3$.
25	,,	$NaCl$.
4	,,	Na_2SO_4.
2	,,	$MgSO_4$.
2·5	,,	$CaSO_4$.
0·12	,,	$NaIO_3$.

Accompanying these constituents there are also potassium sulphate and potassium nitrate (especially in Bolivia), and always earthy impurities, stony fragments, sand, clay, water, and sometimes borates. Caliche may be from snow white, sulphur yellow, lemon yellow to orange in colour, or may be all shades of violet, blue, brown, or grey. Below the caliche layer there is a light-brown loose clay which usually contains sparkling crystals of anhydrite and is known as "coba." The coba forms the floor of the nitrate layers, and below this there is no more sodium nitrate. In secondary deposits—for example, at Salar del Carmen (Antofagasta)—considerable variations may be found from the sequence of the strata in the older deposits.

Ferd. Fischer describes the older method of working at the Officina Rosario, which in 1890 produced 350 tons of saltpetre per day, utilising 880 tons of caliche per day, which contained on the average 40 per cent. $NaNO_3$. The caliche is coarsely crushed in five rock-breakers and then transported in cars with bottom discharge to the top of the boiling pans of the refinery, the cubic capacity of these pans being 12 to 65 cu. m. The refinery works systematically on Shanks' system, and continuously produces hot saturated liquor of about 1·55 specific gravity at 110° to 120° C. The boiling pans are heated by steam coils. The crystallisation requires four

days' cooling. For an output of 350 tons per day 230 wrought-iron crystallising boxes are used, each of 14 cu. m. capacity, and produce about 550 kg. of crystallised nitrate per cubic metre. The cold mother-liquor, which is known as "agua vieja," is run off, and the crystals are drained for twelve hours, after which they are shovelled on to inclined drying stages covered with sheet iron, where they remain for four days in order completely to drain the remaining mother-liquor. They are then transported to the drying and storage bins known as "cancha," in which they are further dried for fourteen days and are then ready for export.

The mother-liquor is returned to the process, after recovering the iodine by treatment with sulphurous acid or sodium sulphite; 500 kg. of sublimed iodine are obtained from 16 operations per day, 18 cu. m. of liquor being treated at each operation. The losses are made good by addition of wash-liquor from the residues, the "relaves," to such an amount only that no evaporation is required.

The final product—that is, the crude nitrate used in agriculture—has the following average composition :—

95·0	per cent.	$NaNO_3$.
2·0	,,	NaCl.
0·6	,,	sulphate, etc.
0·1	,,	insoluble matter.
2·3	,,	moisture.

By allowing the hot liquor from the boiling pans to stand for half an hour or more in steam-heated clarifiers, sodium chloride and a portion of the other impurities separate, and snow-white refined nitrate for chemical purposes is obtained, which contains more than 96 per cent. $NaNO_3$, and not more than 1 per cent. of sodium chloride. Perchlorate is a powerful plant poison. From caliche containing a large amount of this material (2 to 3 per cent.) it is easily separated during the refining processes in the form of the potassium salt.

The method of refining described above is still characteristic of a large part of the Chilean industry, and only recently have attempts been made to introduce more rational methods.

The commercial products, crude and refined nitrate, are shipped from Iquique, Pisagua, Valparaiso, Tocopilla, and other ports. The principal exporters are Gibbs & Co., Weber & Co., W. R. Grace & Co., H. Fölsch & Co., Vorwerk & Co., G. Wilms, and others. The development of the Chilean nitrate industry is shown by the following table of shipments since 1830 :—

	Tons.
1830	850
1840	10,250
1850	23,000
1860	61,650
1870	132,450
1890	1,000,000
1900	1,350,000
1909	2,101,000
1913	2,738,000

Germany absorbed a large portion of the production. Imports into Germany from Chile were :—

1870	20,000 tons.
1895	446,100 tons of the value of 69,000,000 marks (£3,450,000).
1899	526,944 tons of the value of 78,000,000 marks (£3,900,000).
1913	746,800 tons of the value of 166,000,000 marks (£8,300,000).

In other words, in 1913 about 27·3 per cent. of the total Chilean exports of nitrate were imported into Germany. The year 1913 showed a decline in the production of nitrate, as the European consumption, which had increased steadily, showed for the first time a slight decline, namely, 1,810,000 tons in 1913 against 1,930,000 tons in 1912. This decline was shared by almost all the consuming countries, amounting to about 85,000 tons in Germany, 30,000 tons in France, 15,000 tons in Holland, and 5,000 tons in Great Britain. The increased consumption of the Mediterranean countries, of Belgium and of the United States did not completely compensate for the decline in the above-mentioned countries, so that the world's consumption in 1913 was 2·125, million tons, being 75,000 tons less than in 1912 (2·5 million tons). Although this diminished consumption was partly due to the increased price of nitrate in 1913, due to deferred shipments, the increased synthetic production of nitrogen compounds was certainly a contributory cause. The world's production of calcium cyanamide was 153,000 tons in 1912 and 260,000 tons in 1913 ; the Norway nitrate production in 1913 was 73,214 tons. The year was also characterised by the commencement of the production of ammonia in Oppau; the decline was also partly due to an increase in the output of by-product ammonia, the German production of ammonium sulphate from this source being 492,000 tons in 1912 and 549,000 tons in 1913.

Since 1913 the Chilean nitrate industry has developed in quite a remarkable manner. At the outbreak of the War in 1914 a serious crisis occurred, due to the fact that Germany had vanished suddenly

as a large consumer. In 1916, however, the loss of the custom of the Central Powers was entirely neutralised by the growing demand from the United States, which was supplying munitions to the Entente. The continual decrease of the imports into Europe, on account of the German naval warfare in 1917 and 1918, made little difference in this respect, so that the year 1917 was a record in production and 1918 a record in shipment. At the signing of the truce a new crisis in the nitrate industry occurred, the stocks of nitrate in the countries of the Entente, which had been accumulated for the manufacture of ammunition, having been largely disposed of for agricultural purposes, and in 1919, therefore, the production and shipments from Chile were very small. In 1920 business became more lively as the stocks gradually declined. In January, 1920, 183,000 tons were produced in Chile: 103,000 tons in September, 1919; and 162,000 tons in November, 1919. The stocks of nitrate on January 31st, 1920, were as follows: Europe, 150,000 tons (437,000 tons on January 31st, 1914); Egypt, 396,500 tons (691,000 tons on January 31st, 1914); Chile, 1,327,000 tons (484,000 tons on January 31st, 1914). The European imports in January were 212,000 tons. The following statistics summarise the position:—

Chile Nitrate Production.			Chile Nitrate Shipments.	
In mill. quintals of 46 kg.	In mill. tons.		In mill. quintals of 46 kg.	In mill. tons.
60·3	2·774	1913	59·5	2·738
53·5	2·461	1914	(?) 44·1	?2·028
38·2	1·757	1915	44·0	2·023
63·3	2·912	1916	65·1	2·990
65·2	2·999	1917	60·4	2·778
61·2	2·815	1918	65·6	3·018
35·3	1·624	1919	19·7	0·905
49·94 (1920: 60·2)	1·624 (1920: 2·769)	Jan.-Nov., 1920	53·92	2·480

Shipments of Chile Nitrate to Europe and America in Millions of Tons

	1913	1914	1915	1916	1917	1918	1919
Europe and Egypt	1·874	1·245	1·052	1·633	1·063	0·863	0·465
United States [and other countries]	0·864	0·783	0·971	1·309	1·670	2·018	0·440
Stocks in Chile on December 31st of each year	0·170	0·195	0·202	0·697	0·893	0·819	1·551

In spite of the large consumption the visible stock in the United States increased, and was 127,000 tons on December 31st, 1915, 200,000 tons on December 31st, 1916, and 331,000 tons on December 31st, 1917. These figures are expressive of the national endeavour to accumulate a permanent reserve of 350,000 tons of Chile nitrate. They are reckoning in the United States on a 45 per cent. increase in the production for agricultural purposes compared with the former peace consumption, quite apart from the consumption for war purposes.

The result of the War has so far been to nullify any effect of the very great increase of the synthetic nitrogen industry on the Chilean conditions and it has caused a very great rise in prices.

Prices per Quintal of 46 kg. f.o.b. Chilean Ports

	s.	d.		s.	d.
Before the War, average	5	3	to	7	6
1914, average	7	0			
1915	5	8	,,	9	6
1916	7	8	,,	10	0
1917	10	5	,,	14	10
1918	11	6	,,	12	6
1919, average	10	0			
1920	15	6	,,	17	0 (Data from suppliers.)

According to the view of certain producers, this rise in prices, the diminution of stocks, and the increase in shipments, foreshadow a new favourable period for Chile in 1920, which may only be interfered with by the crisis in which the whole world is involved.

War conditions and shortage of shipping have increased freight charges from Chile to an extraordinary extent. Before the War the freight per ton of Chile nitrate was 20*s.* to English and 22·50 marks to German ports. Early in 1920 freights were about £11 for steamers and £9 for sailing vessels, thus accounting for the very great increase in the prices for Chile nitrate. The English prices of Chile nitrate per ton were: £11 5*s.* 6*d.* on 31st December, 1913; £11 2*s.* 6*d.* on 31st December, 1914; £16 5*s.* for the refined product on 31st December, 1915; and £26 in March, 1920, at Liverpool for crude, and £27 at the same port for refined nitrate. These dropped to £25 10*s.* and £26 10*s.* at the end of April, but there was very little agricultural demand at these prices. In Antwerp the price for stocks of nitrate rose from 120 fr. per 100 kg. in the middle of March, 1920, to 145 fr. at the end of April, and spring deliveries in 1921 were offered at 130 fr.

These movements of prices are of some importance for Germany,

as limited quantities of Chile nitrate were already imported in the spring of 1920, and also because, if the bad industrial situation in regard to the supply of coal, etc., continues, further imports of Chile nitrate will be required, in spite of the considerable activity of the atmospheric nitrogen industry, in order to alleviate the most urgent agricultural difficulties. The German stocks of Chile nitrate before the War, on August 1st, 1914, were about 100,000 tons.

In 1907–8 the condition of the nitrogen market was extraordinarily unstable, in consequence of unsound business conditions, inflated promotion, and over-production in Chile. As a consequence, a considerable number of almost obsolete works in Chile had to close. In 1910 53 out of 157 works were closed. At the outbreak of war there were in Chile 170 works, the number of which increased to 173 during 1916–17. The following figures indicate the position :—

On August 31st, 1914	134 refineries were working
On February 1st, 1915	40 refineries were working, of which a large number were only on half production.
July, 1915 .	61 refineries were working.
March, 1916	117 „ „
April, 1916 .	116 „ „
November, 1916	109 „ „
December, 1916	123 „ „
November, 1917	111 „ „
December, 1917	All refineries were working which were able to obtain sufficient fuel supplies ; in the Antofagasta district only a few were closed ; in Tarapacá a few new companies had commenced working.

At the end of 1918 and the commencement of 1919, almost all the refineries were closed.

In October, 1919, two-thirds of the refineries were still closed, but from that date onwards there was an improvement in the production.

The works existing to-day have a total output capacity with intensive working of 4,500,000 to 5,000,000 tons per annum. The profits of some of the companies are shown in the table on p. 15.

A large proportion of the nitrate interests were in English hands—for example, Amelia, Colorado, Lagunas Nitrate, Liverpool Nitrate, London Nitrate, Pan de Azucar, Santa Catalina, Tarapacá & Tocopilla Nitrate, Lilita Nitrate, and others. Recent attempts at amalgamation may be interpreted as attempts to meet the competition of the atmospheric nitrogen industry.

Percentage Dividends

	1916	1917	1918	1919
Angela	21½	25	30	—
Aguas Blancas	10	13½	10	(Loss £18,121)
Anglo-Chilean	25	25	15	--
Fortuna	10	--	7½	--
Lagunas Nitrate	10	10	2 (?)	--
Lautaro	18	24	18	16 per cent.
New Paccha	7½	15	10	--
Rosario	15	17½	--	
Salar del Carmen	15	35	20	5 per cent.
San Lorenzo	25	25	25	--
San Sebastian	10	—	—	(Loss £30,890)
Santa Rita	2½	2½	5 (?)	
Tarapacá	5	15	10	

German interests in the Chilean nitrate industry are very important. H. B. Sloman & Co. A.G. (Hamburg) are the owners of five refineries; together with the German nitrate refineries, Fölsch & Martin Nachf. A.G. and the Saltpeterwerken Gildemeister A.G. (Hamburg), they produced one-seventh of the total Chilean production. The Augusta-Viktoria A.G. recommenced manufacture in 1916–17. The German refineries suffered particularly through the fluctuating exchanges. A considerable period was required in order to overcome the difficulties arising from the fact that those companies which were placed on the English black list were unable to obtain jute sacks. A rumour that the Allies intended to buy up all shares and rights of the German firms in Chile was not confirmed. On the other hand, negotiations lasting over several months ended in 1920 in the sale of certain German nitrate mines, namely Augusta-Viktoria, A.G. Bremen, and A.G. Gildemeister & Co., to the Oestasiatisk Company of Copenhagen. The Sloman A.G. interests also transferred a portion of their property to a new Chilean company in Valparaiso for 16,230,000 marks. The above-mentioned Danish company intend to found an auxiliary company which will exploit the nitrate fields, and it is intended that this shall mainly supply the wholesale exports to Siam, Japan and China. The bonds of the nitrate companies shared in the considerable rise of all securities; the Sloman shares were sold in November, 1919, at 1,220 per cent. (presumably of the par value). The dividends on the Sloman shares were 30 per cent. in 1913; 15 per cent. in 1914, 20 per cent. in 1918, and 10 per cent. in 1919. The Gildemeister A.G.

paid no dividend in 1914, but 10 per cent. in 1913, and 15 per cent. in 1915, 1916 and 1917. Fölsch & Martin A.G. paid 6 per cent. in 1917, 0 per cent. in 1918; the share capital of this company is mainly the property of the Bund Deutscher Landwirte (Union of German Landed Proprietors). This company has recently applied for a considerable increase of capital for the purposes of development. The German producers have joined the Chilean syndicate (1920).

The most important American company which operates in Chile is the Du Pont de Nemours Powder Company. Latterly Japanese capital has also been invested in Chile. Japanese imports of nitrate were 24,000 tons in 1914, and 53,000 tons in 1917. Italian interests are now also active. On the other hand, several English companies, such as the Fortuna Nitrate Company, the Arauco Company and the Alianza Nitrate Company have disposed of their interests to Chilean purchasers (1920). These arrangements have largely been caused by the high British income tax and the unfavourable state of the rate of exchange between the pound sterling and the Chilean peso. According to English reports, the nitrate railways—for instance, the Iquique–Pisagua Railway, the Antofagasta–Bolivia Railway, etc.—paid no dividends in 1919. Their main traffic consists of the transport of nitrate from the producing centres to the Chilean ports.

During the War a central purchasing office for the Entente was established in London. The Association of Nitrate Producers may to some extent be considered as a counter-measure. It was formed in January, 1919, and included 73 per cent. of the refineries. In the first instance the following companies remained outside the union, namely, the Antofagasta and Union Companies, which contribute $10\frac{1}{2}$ per cent. of the production, and the German companies, which contribute $13\frac{1}{2}$ per cent. of the production. At a later date the combination controlled 85 per cent. of the production and was known as the "Association Salitera de Chile" of Valparaiso. A State monopoly of the sale of nitrate was proposed, but was not established. The Association of Nitrate Producers was to continue in the first instance until 30th June, 1921.

The attitude of the Chilean nitrate producers to the atmospheric nitrogen industry is of great interest. At first they did not consider the synthetic processes to be able to compete, but latterly they had to take another view. The endeavours of the German nitrate firms to dispose of their Chilean interests showed how unfavourably they viewed the future of Chile nitrate. The production and sale of Chile nitrate is at present characterised by a greatly increased demand in Spain and Japan (150 to 200 per cent. more than formerly) in the Netherlands (40 to 50 per cent. increase), in Poland, Czecho-Slovakia

and the United States, and also by attempts to improve the methods of manufacture. The production of nitrate in Chile is also encouraged by the fact that the German nitrogen works are unable to produce to the extent originally intended on account of external difficulties, and that large plants which were erected in the United States during the War seem to be considered there as a sort of war reserve, and have been closed. Thus the only serious competitors remaining are Norway, France and possibly Switzerland or England, but these do not seem likely to be of serious influence for the time being. Chilean experts estimate the annual demand of Europe for the next few years to reach about 1,000,000 tons. The exports to Europe and Egypt in 1913 were 1,874,000 tons; America is expected to absorb 500,000 tons to 600,000 tons, and Japan and the remaining countries 200,000 tons to 300,000 tons. (The exports to America and other countries in 1903 were 864,000 tons.) The prospects are considered to be favourable. The further developments of the world's nitrogen production may prove to be in accord both with this view and with the view of the German companies in Chile, in so far as the demand for nitrogen in the impoverished countries, more particularly those of Europe, may be expected to be so large that for the time being they will be able to absorb the output of all the producing groups. For this reason there will probably be no real competition between the natural and the manufactured products for the time being. There is much more likely to be a clear line of demarcation between highly developed industrial states with their own atmospheric nitrogen industry and flourishing coke-oven by-product industries, such as Germany, and countries which are but little developed industrially, but of great future agricultural importance. The former will disappear as consumers of Chile nitrate, perhaps after an intermediate period, and may even, under circumstances, help to supply neighbouring countries; the others, on the other hand, will become larger consumers to the degree to which they resort to artificial fertilisation. Any anticipations of an over-production of nitrogen compounds will probably, therefore, not be realised for the present. At the moment, however, the demand for Chile nitrate has decreased in consequence of the general commercial crisis.

Attempts to improve the methods of production in Chile find their main expression in the formation of the "Institute Cientifici Industrial del Salitre" (1919) by the industrial nitrate magnates; the aim of this institution is the study of all questions connected with the nitrate industry. The present methods of leaching the caliche leave considerable quantities of nitrate in the residue. The pulp which is so obtained, known as "borra," is so rich in nitrate and

in clay-like material that only 50 to 60 per cent. of the nitrate in the caliche is recovered as crystallised sodium nitrate, and the remainder is lost. The old process of boiling is very wasteful, even though no evaporation is required. It has therefore been replaced on an increasing scale by other methods which are used in cyanide leaching. The Agua Santa refineries in Tarapacá made experiments on these lines in 1915. In Chile, first they used simple tube mills and washed the slimes in Butters filters. W. R. Grace & Co. used Burt filters, and the Oficina Peregrina, in Toko, also used Butters filters. At first the Shanks process was still used for the coarser material, whilst the fine material only was treated by the new methods. The process adopted by the English firm of Gibbs & Co. appears to be better. It is described by J. B. Hobsbawn and J. L. Grigioni (J. L. Merriam) in a pamphlet. It depends on leaching with the help of the Dorr classifier, working on the counter-current principle, and also making use of rotary Oliver filters, and finally of vacuum pans. The first experimental installation of this kind, which was sold to the Italian Government, was erected in London in 1914. The Oficina Celia has been working the Gibbs process on a large scale near Antofagasta since December, 1917, and Donald F. Irvin has published very important technical and economic details of the process.[1] The Cia de Salitres de Antofagasta also uses Oliver filters. The Oficina Cristina merely percolates the leaching liquors through the caliche. Various other refineries are experimenting with high-speed centrifuges in order rapidly to separate the slimes from the solution. Prache & Bouillon work with a process, the details of which are not known, by which they are said to recover 17·2 per cent. of nitrate from an 18 per cent. caliche—that is, with a yield of 95·55 per cent., with greatly reduced working costs. Dr. Eduardo Charme claims to have still further reduced the costs by his process, which depends on the precipitation of nitrate from the cold mother-liquor. A modern leaching installation is described by O. Brünler in German pat. 286,742; see also U.S. pat. 1,065,053 and British pats. 23,591 and 26,056/1912.

Neither the methods of obtaining the raw material, which at present lead to the loss of the whole of the more finely divided portion, nor the crushing by means of Blake rock breakers are by any means in conformity with modern practice. The Du Pont de Nemours Powder Company has recently introduced the use of steam excavators in order to reduce the cost of working.

Whilst fear of competition from the synthetic nitrogen industry thus acted as the final incentive to improve the old methods of

[1] *Eng. Min. Journal*, 105, 987, 1st June, 1918.

production, the dearth of potash in countries cut off from the German supplies led to more attention being paid in Chile to the production of potassium nitrate as a by-product. The results are quite remarkable. The Vice-President of the Du Pont Nitrate Company reported on this matter to the meeting of the Delaware section of the American Chemical Society. There is a dispute as to priority regarding the process between the Du Pont Company and R. Nordenflycht, engineer, of Vina del Mar ; it depends on the separation of potassium nitrate from sodium nitrate mother-liquors by cooling. It is said that four to five storage vats for the liquor and one refrigerating machine suffice to produce potassium nitrate at 20 to 30 cents per kilogram. The Du Pont Company, which only accounts for about 1 per cent. of the Chilean nitrate production, produces 10,000 tons annually of a material containing 25 per cent. of potassium nitrate (approximately 1,200 tons of K_2O). It is calculated that by improving this process, which can at present only recover one-third of the potash contents of the nitrate, the total Chilean production of such a product would amount to 720,000 tons per annum (= 86,400 tons of K_2O). The highest potash contents, namely, 1 to 6 per cent., are contained in the caliche of the districts of Tarapacá, Taltal, Antofagasta, and Tocopilla. Nordenflycht states that the calcareous leaching residues from at least 100 of the Chilean refineries contain 1 to 2 per cent. of KNO_3, and that 600,000 tons of potassium nitrate are annually rejected in these residues. The Blanco Encalada Refinery, near Antofagasta, obtains 2 tons of potassium nitrate per day from the mother-liquor, and the Oficina Celia maintains a similar production. The actual production of potassium nitrate of the whole Chilean industry only amounted to 1,100 tons in the last two years, but it is said that 13,500 tons of 99 per cent. quality have been sold for delivery in June, 1920, to the United States.

Paul Menge[1] considers in detail the problem of combining the ammonia soda process with the leaching of caliche, by passing ammonia and carbon dioxide into the solution of the nitrate in order to effect the following changes :—

$$NH_3 + CO_2 + H_2O = NH_4HCO_3$$
$$NH_4HCO_3 + NaNO_3 = NaHCO_3 + NH_4NO_3.$$

The yield of ammonium nitrate which was obtained experimentally amounted to 63 to 70 per cent. only. It is probable that the utilisation of the process on the large scale would be attended with almost insuperable difficulties.

[1] P. Menge, "Über die Frage der Herstellung von Ammonnitrat u.s.w" (On the Question of Ammonium Nitrate Production, etc.), Langen-Salza, Wendt und Klauwell.

Supplement, 1921–24

A very large amount of statistical material will be found in *Chem. Ztg.*, **1921,** 128, 132; **1922,** 84, 147, 264, 464, 472, 524, 691, 1171; **1923,** 84, 107, 176, 199, 256, 285, 355, 364, 455, 492, 520, 537, 592, 612, 688, 699, 739, 748, 764, 792, 824; **1924,** 59; *Chem. Industrie* **1923,** 667; **1924,** 20; *Metallbörse*, **1923,** 61, 112, 208, 839, 935, 1609.

The United States continue to be large buyers in spite of the gradual disposal of their war stocks. On the other hand, the supply to Germany remains very small compared with that before 1924.

Statements on the Chilean production vary, but the following figures are approximately correct:—

	Tons.		Tons.
1915	1,763,639	1920	2,534,728
1916	2,914,542	1921	1,321,000
1917	3,011,811	1922	1,068,000
1918	2,875,902	1923	1,900,000
1919	1,685,768		

The following articles discuss the economic position in Chile:—

Chemical and Metallurgical Engineering, **22** (1920), p. 1207; **22,** p. 655; **23,** p. 339.

Chemical and Technical Summary in *Chem. Ztg.*, **1921,** 117.

The following patents relating to improvements in the methods of manufacture are important (*Chem. Ztg.*, **1922,** 1032); U.S.A. pats. 1,356,806 and 1,357,273; British pat. 182,859/1922.

Butter's leaching process: *Metallbörse*, **1923,** pp. 318, 558.

General articles on measures taken in Chile for the development of the industry: *Chem. Ztg.*, **1922,** 105; **1923,** 199, 432, 834; *Chem. Industrie*, **1923,** 409, 556, 607, 639; *Metallbörse*, **1923,** 552, 907, 1094.

PART I

HISTORICAL AND ECONOMIC SECTION

CHAPTER III

The Development of the Atmospheric Nitrogen Industry in Germany and its Economic Foundations

THE exceptional difficulties with which the nitrogen industry and agriculture were faced in Germany on the unexpected outbreak of war in August, 1914, will be obvious if we compare with the home production the imports of Chile nitrate which suddenly disappeared, and which amounted in 1913 to 746,800 tons, containing about 15·5 per cent. of nitrogen, approximately equivalent to 116,000 tons of nitrogen. In 1913 the internal production consisted mainly of 549,000 tons of ammonium sulphate, of which 85 per cent. was supplied by coke ovens and 15 per cent. by gas works. These two sources together produced 199,800 tons of nitrogen as ammonium sulphate containing 20 per cent. of nitrogen. There were also produced in Germany about 24,000 tons of calcium cyanamide containing 20 per cent. of nitrogen, equivalent to 4,800 tons of nitrogen, and about 20,000 tons of Haber ammonium sulphate containing 20 per cent. of nitrogen, equivalent to 4,000 tons of nitrogen. The total German consumption of nitrogen compounds in 1913 is given in the following table :—

	Tons of Nitrogen.
(1) Ammonium sulphate, about 460,000 tons	92,000
(2) Norwegian saltpetre (imports), 35,000 tons	4,500
(3) Calcium cyanamide, 30,000 to 50,000 tons	6,000 to 10,000
(4) Haber ammonium sulphate, about 20,000 tons	4,000
Total . .	106,500
To this must be added :—	
(5) Chile nitrate, 746,800 tons .	116,000
Grand total, about	222,500

This consumption in time of peace was partially met by a home production of :—

	Tons.		Tons of Nitrogen.
(1) By-product ammonium sulphate from coke ovens, etc.	549,000	=	119,800
(2) Haber ammonium sulphate	20,000	=	4,000
(3) Calcium cyanamide, about	24,000	=	4,800
Total			128,600

This is on the assumption that all exports ceased and that neither Norwegian nitrate nor calcium cyanamide could be imported from abroad. As is well known, these were the actual conditions.

A survey of the development of the German trade in fertilisers is given by the following table :—

Imports in Tons

January–August, 1920	25,930
January–August, 1913	41,442

Exports in Tons

January–August, 1920	5,510
January–August, 1913	68,237

Exports in Millions of Marks

January–August, 1920	3·4

According to Camille Matignon, the stocks of Chile nitrate at German ports on 1st August, 1914, were 45,000 tons ; the stocks of ammonium sulphate were more than 100,000 tons. To these must be added the quantities which were already in the hands of consumers, which were not very large—perhaps about 55,000 tons of nitrate—and finally the stocks which were captured in Antwerp, Ostend, Ghent, and Bruges, altogether 32,000 tons of nitrate. The military requirements, which increased at an extraordinary rate, caused these stocks to disappear extremely quickly, although at first the relationship between supply and demand appeared fairly satisfactory. Walther Rathenau, who took over the administration of the "Department for Military Raw Materials" in August, 1914, described the whole position at that time in a paper which he read on 20th December, 1915, before the "German Society of 1914" as follows : "September arrived and the War developed. We repeatedly carried out our calculations, and always compared them with the information supplied by the consuming centres. We repeatedly obtained the answer, 'The demand is covered.' We were then suddenly worried

by the consideration, 'How shall we stand if the War on the Eastern front attains the same dimension as in the West?' 'Or if the War becomes more severe and more widely developed than we can imagine at present, what shall we do then about nitrogen supplies?' No solution could be found to these questions. It was a heavy morning on which I explained the position to the acting Minister of War and asked permission to allow an indefinite number of chemical works to be erected, that is to say, as many as the chemical industry could manage. The Minister of War, His Excellency Von Wandel, in his broad-minded, quiet and determined manner, immediately gave authorisation to enter into negotiations with the chemical industry. Exceedingly valuable preliminary work of a technical character had already been carried out. Professors Fischer and Haber had worked out the problem of nitrate production on a very large scale in a manner for which we are greatly indebted, and the chemical industry was not in the least surprised when it was faced with the problem of undertaking these manufactures. The erection of a considerable number of works was agreed to, and the chemical industry was so confident and trustful that they agreed that the work should be started before I was in a position to send them the agreement confirmed by the Treasury. The works were roofed in before the agreement was signed—that is, at about Christmas. The industry of atmospheric nitrogen had become a German industry, a world problem had been solved, and the most serious War danger of technical character had been prevented. The industry which was brought into being under the urgent necessity of war is to-day a beneficent factor in German agriculture. The atmospheric nitrogen works, coke ovens, and gas works succeeded in satisfying the enormously increasing demands, so that the nitrate blockade, which was very soon effective, was unable to produce very devastating results. Only 3,940 tons of nitrate entered Germany from August to December of 1914."

The statistics given above indicate a total demand of 222,500 tons of nitrate annually. Of this demand at least 200,000 tons were utilised by agriculture. During the War the agricultural interests had to content themselves with 100,000 tons of nitrogen per annum, and after the close of the War this figure unfortunately did not increase at such a rate as would have been desirable in the interests of the food supply of the German nation. It is commonly assumed that German agriculture could manage quite successfully with about half the normal quantity of nitrogenous fertilisers—that is, with 100,000 tons of nitrogen instead of the former quantity, 200,000 tons annually. Neubauer, of Bonn, has shown in the *Zeitsch. f. angew*

Chem., 1919, II., 437, that these calculations are erroneous. He bases his views on the very careful statistics of Kuczynski and Zuntz in the 9th volume of the "General Statistical Archives" for the year 1915, according to which Germany imported 180,000 tons of nitrogen in 1913 in the form of valuable foodstuffs, including, for example, 3,000,000 tons of barley from Russia. Now, if we introduce 100 parts of nitrogen into the soil as a fertiliser, we do not obtain a return of more than at most 50 parts as vegetable albumen, so that in order to produce internally these 180,000 tons of nitrogen in food it would be necessary to employ twice 180,000 (= 360,000) tons of nitrogen in fertilisers, additionally to the amount normally used in time of peace for agriculture.[1] By using 100 kg. of Chile nitrate per hectare of agricultural land, an increased crop is produced of 300 to 400 kg. of grain; therefore, at least 750,000 tons of Chile nitrate would theoretically be necessary in order to replace the 3,000,000 tons of imported Russian fodder barley. We can see from these considerations how large the German demands for nitrates really are, and what an extraordinarily fundamental reaction the lack of nitrogen has had, and must in the future have, on the whole question of nutrition :—

German Agriculture

	Required	and	Received in 1919.	Tons of Nitrogen
At least	200,000 tons of nitrogen in fertilisers; and		250,000 tons of ammonium sulphate	50,000
	180,000 tons of nitrogen in fodder, corresponding to a further		Synthetic products	60,000
	360,000 tons of nitrogenous manure		In small quantities of imported fodder, about	5,000
Total about	560,000 tons of nitrogen.		Total about	115,000

Naturally, in this table only imported fodder has been considered, and the incorrect assumption has also been made that the use of farmyard manure is as extensive as in pre-war times, also that the other circumstances—for example, the inland food supplies—have remained the same as before. This very unsatisfactory balance also shows the extreme importance of the German atmospheric nitrogen industry, which produces 500,000 tons of fixed nitrogen per year, but might have produced much more had it not been for the many interferences with production which have occurred since the Revolution. In 1920 the conditions improved. At Easter, 1921, there were, however, further difficulties caused by the communistic riots at Leuna. The poor output during the last few years cannot, however, detract from

[1] The assumption is here made that the soil is capable of producing these increased harvests.

the enormous services rendered by the German atmospheric nitrogen industry. These were recognised by the presentation of the Liebig Medal of the Verein Deutscher Chemiker to F. Haber in 1914 and to C. Bosch in 1919, by the award of an Honorary Doctorate to N. Caro in 1921, and, finally, by the still more brilliant recognition through the award of the Nobel Prize to F. Haber in 1918.

The calcium cyanamide industry was the first of the nitrogen fixation industries to be carried out on a commercial scale in Germany. In the course of a critical study of the fixation of atmospheric nitrogen, A. Frank and N. Caro [1] came to the conclusion that in the usual synthesis of cyanide, carbide might possibly be formed as an intermediate product, which might perhaps itself be capable of fixing nitrogen. A year previously, in 1894, H. Moissan unsuccessfully attempted to nitrogenise pure calcium carbide at 1,200° C., but, in spite of this, the conclusion of A. Frank and N. Caro proved to be correct. They showed in German pat. 88,363 that under certain conditions fixation of nitrogen occurred. At that time they assumed that the reaction followed the following equation :—

$$CaC_2 + N_2 = Ca(CN)_2,$$

and, in co-operation with the younger Frank, they made a more careful study of the conditions, hoping to produce a more practicable and economic method of preparing cyanide.[2] The Dynamit-A.G. vorm. Alfred Nobel & Co., Hamburg, erected an experimental plant under the direction of Frank and Caro, in order to investigate the process technically.

A later German patent, No. 92,587, which uses ammonia as a source of nitrogen, was mainly taken out as a protection against imitation. Although the first technical attempt to fix atmospheric nitrogen directly failed, Frank and Caro followed up their idea energetically (German pat. 95,660), and first combined for this purpose with the Siemens and Halske A.G. in Berlin.[3] H. Mehner had carried out a series of experiments jointly with Siemens and Halske, and with Schlutius at Halle, with the object of fixing nitrogen, not by finished carbide, but by a so-called carbide-generating mixture, that is, by a mixture of calcium or barium carbonate and coal heated to a high temperature in the electric furnace.[4] They

[1] Compare N. Caro, "Die Synthetischen Methoden der Cyankaliumfabrikation," *Chem. Ind.*, 1895, Nos. 12/13; *Zeitsch. f. angew. Chem.*, 1906, p. 1569; Siebner, *Chem. Ztg.*, 1913, pp. 1057, 1073.

[2] B. Waeser, "Fortschritte der anorganischen Grossindustrie in den Jahren 1905 bis 1912," *Chem. Ztg.*, 1913, Nos. 110 to 154/155.

[3] C. Krauss, in Ullmann's "Encyclopædia," vol. III. (1916), pp. 205-222.

[4] G. Erlwein, *Zeitsch. f. angew. Chem.*, 1903, pp. 520, 533, 537; *Zeitsch. f. Elektrochemie*, 1906, pp. 551, 665.

also endeavoured to fix atmospheric nitrogen by a tubular carbon cathode in an electrolysed barium cyanide melt (German pats. 91,814, 94,493, 151,644). These experiments, the technical portion of which was carried out by a "Stickstoffgesellschaft" founded in Berlin in 1905, did not achieve the desired results. Frank and Caro and Siemens and Halske A.G. had also arrived at similar results. The "Siemens compound" which was obtained, contained a maximum of 12 to 14 per cent. nitrogen. Neither did the investigations of the Badische-Anilin- und Soda-fabrik lead to a satisfactory result (German pats 149,803 and 190,955).

Further investigations carried out by A. Frank and N. Caro, the Dynamit-A.G. vorm. Alfred Nobel & Co., of Hamburg, H. Mehner, F. Rothe, H. Freudenberg and Siemens and Halske A.G., Berlin, together with Erlwein and Voigt, were much more important. In the winter of 1895–96, F. Rothe had studied the nitrogenation of carbide with the firm of A. Beringer & Söhne of Charlottenburg. The latter firm, however, were unable to complete their patent application, B.20,334, which emphasised the use of dry, pure nitrogen. In 1897, F. Rothe entered the service of A. Frank and N. Caro in order to work in accordance with their instructions, and more particularly in order to search for the supposed cyanamides. In the spring of 1898, it was proved that the carbides of the alkaline earths and nitrogen did not actually form cyanides, but cyanamides, according to the following equation:—

$$BaC_2 + N_2 = BaCN_2 + C.$$

The results of these investigations are embodied in German pats. 108,971, 116,087 and 116,088. The following observations, which were of importance for the large industry which resulted, were then made. It was found that cyanamide was mainly produced when thin layers of finely ground carbide were nitrogenised, and that, on the other hand, cyanide is obtained from coarsely crushed carbide: also that barium carbide is more inclined to the formation of cyanide, whilst calcium carbide mainly forms cyanamide, and, finally, that the most favourable reaction temperature when using barium carbide is 700° to 800° C., and with calcium carbide 1,000° to 1,100° C. It was also found that apart from the main reaction described above, under circumstances, the following reactions may also occur:—

$$CaC_2 + N_2 = Ca(CN)_2$$
$$Ca(CN)_2 + N = CaCN_2 + (CN).$$

The occurrence of these latter reactions is confirmed by the fact that paracyanogen is occasionally formed. During these investigations

attention was exclusively directed to the production of cyanide. Finally, the Cyanidgesellschaft G.m.b.H.[1] of Berlin was founded on July 29th, 1899, by A, Frank, N. Caro, Siemens & Halske A.G., and the Deutsche Gold- und Silberscheideanstalt of Frankfort-a.-M. The Scheideanstalt had already investigated these same problems independently. The associated interests having thus been consolidated, work was carried out on the experimental plant of the Scheideanstalt as follows : Barium carbide was treated with nitrogen in closed iron retorts at a red heat, the reaction product fused with sodium carbonate, and the resultant mass leached. The barium carbonate thus reproduced was returned to the process ; the sodium cyanide was converted into potassium ferrocyanide by treatment with iron carbonate and the resultant solution evaporated *in vacuo*. Attention was ultimately diverted from the barium compound to the cheaper calcium carbide, mainly at the instigation of the head chemist of the Scheideanstalt, Dr. Pfleger. Cyanide, which was obtained as above, was decomposed with hydrochloric acid, and the prussic acid which was obtained was absorbed in sodium or potassium hydroxide solution. Increasing attention was meanwhile directed to those remarkable intermediate products, the cyanamides. H. Freudenberg, the research chemist of the Scheideanstalt, and A. Frank, independently and almost simultaneously suggested the use of these nitrogenous and non-poisonous compounds as fertilisers. The very complicated patent situation is reviewed with the help of detailed references by K. W. Jurisch in his book " Salpeter and sein Ersatz " (Leipzig, 1908, S. Hirzel). In order to eliminate all patent litigation, the patent dealing with fertilisers, German pat. 152,260 of May 1st, 1901, was transferred to the Cyanidgesellschaft, Berlin. The first experimental trials with the new fertiliser by Gerlach, P. Wagner and others, showed that cyanamides are not plant poisons, but form ammonia in the soil, and can be recommended as good fertilisers. The suggestion to decompose calcium cyanamide with water with formation of ammonia and calcium carbonate is first made in German patent 134,289 of November 25th, 1900, which is in the name of A. Frank.

The above-mentioned interests worked conjointly until the middle of 1901; the Deutsche Gold- und Silberscheideanstalt then separated from the others, being mainly interested in cyanide compounds, in

[1] Max Steinthal, Hecht, Pfeiffer & Co., and others were also interested. The Cyanidgesellschaft G.m.b.H. was at first purely an association for experimental purposes, but afterwards erected the Stickstoffwerke Spandau for the production of potassium cyanide. At the instigation of M. Steinthal, of the Deutsche Bank, the Bayrischen Stickstoffwerke A.G. was founded in 1908 by the Deutsche Bank, with the co-operation of a number of Berlin and Munich bankers and of firms associated with the fertiliser industry.

regard to the production of which they had already followed a divergent path. A. Frank and N. Caro worked at the further perfection of the process with the firm of Siemens & Halske A.G. at the research department of the electro-chemical works at Martinikenfelde, near Berlin. They soon succeeded in raising the absorption of nitrogen by the carbide to 80 to 85 per cent. Meanwhile Polzenius, who was at that time chemist to the Polack Accumulator Works, Frankfurt-a.-M., which had gone into liquidation, found that the temperature of reaction could be lowered from 1,000°–1,100° C. to 400°–500° C. by adding calcium chloride which had previously been ignited at a high temperature (German pat. 163,320). In Germany Frank and Caro at first sold their product as "Frank-Pfleger-Masse" containing 10 to 20 per cent. of nitrogen, but later as "Kalkstickstoff" ("lime-nitrogen") containing 14 to 23 per cent. of nitrogen; Polzenius described his product, containing a similar percentage of nitrogen, as "Stickstoffkalk" (nitro-lime). These distinctions are now no longer made; both products are now dealt with under the same name of "Kalkstickstoff" (nitro-lime).

The Polzenius patent was transferred to the A.G. für Stickstoffdünger G.m.b.H. at Westeregeln, near Magdeburg, which marketed considerable quantities of nitro-lime in 1905, namely 800 tons. The Westeregeln plant worked at full capacity until 1909; it was gradually closed during 1910–11, after manufacture had been taken up by the A.G. für Stickstoffdünger at Knapsack, near Cologne, which was founded in 1906. The business year, 1908, showed a loss of 36,042 marks, which increased in 1909 to 223,062 marks (about £11,000). In consequence of the general over-production, the Knapsack plant only produced a small proportion of its output capacity in 1909, in spite of the fact that the Sales Association (see p. 30) had increased the total sales by 35 per cent. In 1909 the Knapsack Works took up the manufacture of ammonium sulphate, but did not proceed that year beyond somewhat large trials, which were by no means satisfactory. Caro was the first to show that the nitrogenation process was exothermic. The capital cost of plant is greatly decreased by internal heating and progressive reaction from within to without. Addition of calcium chloride produces no technical effect of any kind, beyond the reduction of the reaction temperature; it merely increases the production cost by the cost of the calcium chloride.

In the interval, the Frank-Caro group had not been idle. The Società Italiana di Prodotti Azotati had commenced production in Piano d'Orta, where it utilised the water power of the Pescara in the Abruzzi in 1905. The parties mainly concerned in the foundation

of the company were the Cyanidgesellschaft G.m.b.H., of Berlin, and the Deutsche Bank. The works were originally intended for an output of only 4,000 tons of nitro-lime per annum, but this was increased to 14,000 tons in 1912 and 24,000 tons in 1913. The first German undertaking to operate the Caro process was the Bayrische Stickstoffwerke A.G. at Trostberg, in Upper Bavaria, founded in 1908. The company, which is closely connected with the Deutsche Bank, utilises the water power of the Alz (16,000 h.p.). In 1915 to 1916 the company commenced to develop a second stage of 24,000 h.p. at Tacherting-Margarethenberg. The first business year during which the plants were in full operation throughout was 1912–13, and showed a dividend of 9 per cent. A ready sale was found for most of the ammonium sulphate produced, and, in consequence, the share capital was increased in 1912-13 to 8,000,000 marks, and the works were further extended. The output-capacities in tons of nitro-lime were stated to be as follows :—

	1912	1913
Trostberg . . .	15,000	25,000
Knapsack . . .	15,000	25,000

The actual total production was 22,000 tons in 1912 (of which 20,000 tons were from Trostberg), and 24,000 tons in 1913. The prices were as follows :—

Quoted in Berlin.	A Quality (17/22 per cent. N). Marks per 1 kg. per cent.		B Quality (15/16 per cent. N). Marks per 50 kg.	
	19/3/13	13/12/13	19/3/13	13/12/13
	M.	M.	M.	M.
10-ton lots . . .	1·18	1·14	9·40	9·00
5-ton lots . . .	1·20	1·16	9·60	9·20
3-ton lots . . .	1·23	1·19	9·80	9·40
Smaller lots . .	1·26	1·22	10·00	9·60

Prices for December, 1913, for spring delivery in 1914, were quoted under the following conditions : Free delivery to any German State railway station, or light railway station ; if acceptance was delayed beyond January 20th, 1914, an additional 40 marks per 10 tons were to be charged for storage.

The Frank-Caro group, that is, the Cyanidgesellschaft G.m.b.H. Berlin, founded the Ostdeutschen Kalkstickstoffwerke und Chem. Fabriken G.m.b.H., of Berlin, which was an affiliated company to the Brandenburgischen Carbid und Elektrizitätswerke A.G., Berlin,

which paid a 7 per cent. dividend in 1919–20. The last-named company utilises the following water powers : 2,200 h.p. at Mühltal, near Bromberg, obtained by damming the Brahe ; 1,400 h.p. at Steinbusch, near Kreuz ; 2,200 h.p. at Borkendorf, near Schneidemühl, and 500 h.p. at Schneidemühl, being a total of 6,300 hydraulic horsepower. The Ostdeutschen Kalkstickstoffwerke have never come into regular operation ; it was intended to utilise 2,000 h.p. for the production of nitro-lime at Mühltal (which is now Polish). The whole plant was much too small for profitable production, and was closed in 1914–15. Since that date the Steinbusch and Mühltal works produce carbide only ; naturally, considerable quantities of electric power are sold to other interests. The Steinbusch works were closed during 1919–20. The Brandenburgischen Elektrizitätswerke also owned the Norsk Electro-kemisk Aktieselskabet, which produces carbide, etc.

In 1913, the A.G. für Stickstoffdünger in Knapsack founded the Mitteldeutschen Stickstoffwerke G.m.b.H., which was originally at Frankleben, but soon moved to Gross-Kayna. The firm has a capital of 1,000,000 marks, the main participants being the A.G. für Stickstoffdünger and also the Michel Company, which was formed by Rhenish financiers. The works of the Mitteldeutschen Stickstoffwerke Gross-Kayna were at least partially in operation in 1914–15, and first showed a small profit in 1915. The report of the Knapsack company described the fall in prices in the nitrogen market at the end of the first-half of 1914 as a collapse caused by the increase in domestic production and the exceptionally large imports of foreign artificial and natural fertilisers. Gross-Kayna has meanwhile been definitely closed, and was to be leased to the Elektrizitätswerk Sachsen-Anhalt A.G. in 1920 as a power station of 20,000 k.w.

Before the War the output was sold by the Verkaufsvereinigung für Stickstoffdünger G.m.b.H., of Berlin, to which English, French, Italian and German firms belonged, and also by the International Carbide Syndicate. Both were dissolved in 1914–15, the former by order of the Courts.

At the outbreak of war, therefore, production in Germany was essentially confined to the Trostberg and Knapsack works, the total output capacity of which was from 36,000 to 60,000 tons of nitro-lime annually. There were two groups of interests—namely, the Frank-Caro process, with works at Trostberg and Mühltal, and the Polzenius process, with works at Westeregeln, Knapsack and Gross-Kayna. They differed not only in the processes which they exploited, but also by the fact that the Frank-Caro group utilised water power and the Polzenius group power from fuel, namely, from quarried lignite from

the Rhineland and the Province of Saxony, in order to obtain carbide as cheaply as possible. C. Krauss, the director of the A.G. für Stickstoffdünger at Knapsack, ascribes the considerable transference of the nitro-lime industry to foreign countries to the tendency to utilise water power. He writes as follows:[1] "Till very recently the view was held that the rational manufacture of carbide was only possible by the utilisation of cheap water power, and the nitro-lime production of both the Frank-Caro and the Cyanide groups was almost entirely based on its exploitation. As such water power was very scarce in Germany, this originally purely German invention has unfortunately fallen into the hands of foreigners, who have erected large works in Norway, Italy, Dalmatia, and France, from which countries they inundate the German market with nitro-lime." In peace time the price per k.w.h. produced with Upper Bavarian water power could be estimated at ¾ pfg. and from Central German quarried lignite at about 1 pfg.

During the War, when anxieties arose with regard to the German supply of nitrogen compounds, the existing nitro-lime works increased their productive capacities; the erection of the Gross-Kayna works in the valley of the Geisel, near Merseburg, was accelerated, the capital of the A.G. Stickstoffdünger was increased in the spring of 1915 from 3,000,000 to 8,000,000 marks, and that of the Bayrischen Stickstoffwerke, of Munich (Trostberg), was raised to 12,000,000 marks in 1915 to 18,000,000 marks at a later date, and to 30,000,000 marks in 1921. Simultaneously the State interested itself in the nitrogen industry in consequence of the decisions of the Department for Military Raw Materials of the War Ministry, which have already been referred to. In 1915, the Bayrischen Stickstoffwerke, of Munich, established a branch in Berlin, and later removed their head office to that town. In March, 1915, they took over the erection and works control, on behalf of the German Government, of the large nitrogen works which had been erected in 1915–16 at Piesteritz, near Halle, at Wittenberg-on-Elbe, and at Chorzow, near Beuthen. The works were erected at the cost of the Government, and all the profits accrued to the State. In order to hasten the completion of the work, the utilisation of water power was dispensed with, and power from coal was used. The Piesteritz Nitrogen Works, which were built in the interval from March, 1915, to Christmas, 1915, receive their electricity supply from the large power station at Golpa-Zschornewitz, 25 km. distant, close to Bitterfeld, whilst the Chorzow works are supplied with 30,000 k.w. from the Oberschlesischen Elektrizitätswerke (Upper Silesian

[1] "Ullmann," vol. iii., p. 206.

Electric Works), the central power station of which is in the immediate vicinity. A further 30,000 k.w. were produced by Chorzow at their own power station. These works will be further described later; it may at once be mentioned here that Piesteritz is by far the largest German works, and has an output capacity of 400 to 450 tons of nitro-lime daily, produced by the Frank-Caro process.[1] It orginially comprised 8 carbide furnaces (330 tons of carbide), and later had 10 carbide furnaces. The distribution of the nitro-lime from the State works was handed over to the Deutsche Landwirtschaftliche Handelsbank G.m.b.H., of Berlin. The output of the State factories was primarily intended for agricultural purposes. Nitro-lime was certainly for the time being the most suitable artificial nitrogenous fertiliser, as the nitrogen which it contains is, so to say, primarily combined with lime, without the help of an acid. It was found possible to supply agriculture during the harvest of 1916–17 with approximately 100,000 tons of nitrogen, which is half the peace consumption in 1913, or the total consumption in 1909. Unfortunately the increasing shortage of coal, limestone, and power prevented any appreciable improvement of these conditions. On the contrary, they rapidly became worse after November, 1918, so that finally in 1919 the unfortunate position which has already been described was necessarily reached. The prospect has only improved quite recently. Piesteritz works have acquired their own lime works in the Harz, which have been leased for ten years in the first instance and are known as Gewerkschaft Harz-Blankenburg, with plants at Hüttenrode and in Kalten Tal, near Rübeland, the present firm being Braunschweigische Harzkalkwerke A.G.

The Piesteritz interests were converted into a joint stock company, the Mitteldeutschen Stickstoffwerke A.G., in 1920, with a capital of 120,000,000 marks. The Chorzow works were converted into the Oberschlesischen Stickstoffwerke A.G., with a present share capital of 110,000,000 marks. These works, together with the central power station in Golpa (which was acquired by the Imperial Treasury in the autumn of 1917), are now the property of the First Administrative Division of the Industrial Section of the Imperial Treasury in Berlin.[2]

The German State is also financially interested in the Upper Bavarian works of the Bayrische Stickstoffwerke. Under the heading "Bayrische Stickstoffwerke A.G.," the report of the Deutsche Bank in 1917, is as follows: "The Company has obtained from the Bavarian Government the prior concession for the exploita-

[1] The agreements and other particulars relating to the Chorzow works are described in *Chemical Trade Journal*, and in *Chemical Engineering* of 22nd May, 1920, p. 665.
[2] Chorzow works are now in Polish territory (*Translator*).

tion of the water-power of the Lower Inn comprising about 200,000 h.p. With very considerable help from Bavarian banks and firms our financial directorate has formed a syndicate to prepare for this undertaking, the completion of which will require a capital of more than 150,000,000 marks." These gigantic projects, which are interconnected with other State plans relating to electric supply, the production of aluminium, and so forth, have had to be postponed for the present. The dividends of the Bayrische Stickstoffwerke were 8 per cent. in 1914, 12 per cent. in 1915, 14 per cent. in 1916, 14 per cent. in 1917, 11 per cent. in 1918, and 12 per cent. in 1919. In 1920 a new company was formed, the Bayrische Kraftwerke A.G., of Munich, with a preliminary capital of approximately 1,000,000 marks.

During the War the A.G. für Stickstoffdünger at Knapsack worked at its maximum output of about 200 tons of carbide, corresponding to about 250 tons of nitro-lime containing 20 per cent. of nitrogen. The dividends were 8 per cent. in 1913, 6 per cent. in 1914, and 10 per cent. in 1915. In 1915 the works entered into close relationship with the Höchster Farbwerke, which were partially supplied from Knapsack with ammoniacal liquor for conversion into nitric acid by oxidation; ultimately the Farbwerke acquired the greater part of the shares. The Knapsack works were not allowed to publish any business reports for 1915–16 and 1916–17, on account of the state of war; the gross revenue was 1,351,266 marks in 1914–15, and 6,862,402 marks in 1917–18; on the other hand, the expenses had risen from 217,219 marks in 1914–15 to 1,073,736 marks in 1917–18, and the amounts written off from 684,081 marks in 1914–15 to 5,146,585 marks in 1917–18; the effect of these heavy charges was that in the year 1917–18 a loss of 204,318 marks was made instead of a dividend of 8 per cent. in 1916–17. In 1919–20 the dividend was 6 per cent. The company ascribed these poor results to the coal tax, the high prices of raw materials, high wages and salaries, and also more particularly to the unsatisfactory fixation of prices by the authorities, who had fixed prices for nitro-lime and for ammonia which had no relation to actual circumstances. At that time the Directorate already held the view that it was uncertain whether it would be possible to continue manufacture. The occupation of the Rhineland rendered the circumstances still worse. The Farbwerke vorm. Meister, Lucius & Brüning, of Höchst-a.-M., (Höchster Farbwerke) were considerably interested, not only in the supply of ammonia from the Knapsack Company, but also in their production of carbide. During the War carbide manufactured at Knapsack was used to a considerable extent in the manufacture of acetone for the

synthesis of indiarubber. The acetylene evolved from calcium carbide is converted into acetaldehyde by addition of water in presence of catalysts, and this compound is then oxidised to acetic acid. When passed through a contact material this compound forms acetone, with liberation of carbon dioxide. As is well known, this acetone is converted into artificial rubber by reduction to pinacone by means of aluminium and the conversion of this compound into dimethyl-butadiene, which is the mother-substance of methyl-caoutchouc. The Höchster Farbwerke erected new plants at Knapsack for the manufacture of acetone by the methods indicated; the same firm, and also the Farbenfabriken vorm. Fr. Bayer & Co., of Leverkusen, converted this acetone into methyl-caoutchouc, of which about 150 tons per month were finally produced. Under present conditions synthetic caoutchouc is unable to compete with the natural product, and the manufacture has therefore been dropped. The manufacture of alcohol and acetic acid from carbide will be described later; for some time this manufacture formed a monopoly of the Höchster Farbwerke within the "Interessengemeinschaft" of the dyestuff companies. The preference given to the carbide interests gave rise to the following enquiry of the Deputies, Drs. Meerfeld, Röhl and Sollmann, to the German Government in 1920: "According to reliable information, the A.G. für Stickstoffdünger at Knapsack, near Cologne, has ceased to produce nitrogenous fertilisers, instead of which they are only producing carbide, which yields a larger profit to the company. In this way agricultural interests, which are in any case suffering through lack of fertilisers, are still further prejudiced. What does the Imperial Government intend to do in order to ensure that the company mentioned will once more produce nitrogenous fertilisers in the interests of the national food supplies?" The Imperial Ministry of Industry gave the following answer: "No decrease in the production of nitrogen compounds at Knapsack is to be expected. The company had only expressed its intention to cease the production of nitro-lime, but has not already done so, as would appear from the question. The application of the company for an increase in the sale price has been agreed to, and the increased production costs which have been incurred in the interval will be repaid to it in full from the compensation fund. The administration of the compensation fund have also assured the company that they will recompense them in full for any further increases in the cost of production which may occur until the middle of May. It should be added that Knapsack, in common with other nitrogen works, has always sold a small amount of carbide, which is extremely necessary for lighting purposes, and that these supplies will be continued."

According to a memorandum of the Under-Secretary of State, Hirsch, of the Imperial Ministry of Industry, the so-called compensation fund represents an attempt which was initiated during the War to forcibly direct private capital into channels of utility to the community. For example, the compensation fund for the nitrogen industry, which we are here considering, is, in the first instance, to be used for assisting those works which are least profitable, and, secondly, to finance imports of foreign raw material. In Knapsack, the Siemens and Stinnes interests founded the Rheinische Elektrodenfabrik G.m.b.H. in 1917, which undertook a part of the supply of electrode-carbons to the A.G. für Stickstoffdünger.

The Elektrizitätswerk-Lonza A.G., of Bâle, founded in 1898, manufactured nitro-lime before the War in their works at Gampel (at the confluence of the Lonza and the Rhone); they used the Polzenius process. The German branch of this company, the Lonzawerke, Elektrochemische Fabriken G.m.b.H., at Waldshut, Baden, at first produced carbide only. During the War the German Government granted them considerable credits in order to establish nitro-lime manufacture at their works, this industry having only just been initiated at the time. Apart from this German branch of the Swiss firm, the remaining German-Swiss carbide and calcium cyanamide works in Switzerland (at Gampel and the Gotthard-Works at Bodio) took a considerable part in supplying Germany; thus in 1915 the Swiss exports of carbide were 55,413 tons, of which 48,634 tons went to Germany: in 1916, 46,630 tons went to Germany out of 58,010 tons total exports, and, in 1917, 37,843 tons to Germany out of 59,448 tons.

The total maximum output capacity of the present German calcium cyanamide factories—namely, Trostberg, Piesteritz, Chorzow, Knapsack, Gross-Kayna and Waldshut—amounts to 115,000 tons of fixed nitrogen, that is, about 600,000 tons of calcium cyanamide. For the reasons already mentioned, the actual output, for example, in 1918, was only about 300,000 tons. The general difficulties in the supply of raw materials and of manufacture were very great during the War. Thus the Mitteldeutschen Stickstoffwerke at Gross-Kayna, near Merseburg, were closed entirely for a considerable period. After recommencing production in March, 1918, they had to close once more after a short period, on account of coal shortage, and did not start production again. The same circumstances occurred, among other places, at the limestone quarry at Niedercho of the A.G. für Stickstoffdünger. We may assume the German production of nitro-lime in 1913 to have been 24,000 tons, to which about 20,000 tons of Norwegian manufacture may be added, and the

maximum output capacity at that date was about 50,000 tons; thus the production during the War (until 1918) increased at least twelve and a half times, and the maximum output capacity at least twelve times, apart from the year 1919, which suffered from political disturbances. A similar enormous increase in the production of nitro-lime since 1914 has occurred in France only. The figures relating to that country are :—

	Production.		Maximum Output Capacity.
1914 . . .	7,500	..	7,500
1918 . . .	100,000	..	300,000

The world's production of calcium cyanamide in 1918 is estimated to have been in round figures 1·325 million tons, containing 20 per cent. of nitrogen, and in 1919 about 1·715 million tons, containing 20 per cent. nitrogen. The last figure is presumably based on maximum output capacity, which is well known not to have been attained anywhere. Actually the production of Germany, which was the largest producer, was 22·64 per cent. of the actual world's production in 1918.

The development of the production of calcium cyanamide in Germany is so closely associated with the rapid development of the calcium carbide industry that it is essential that this should be discussed to some extent; we have based our information on the excellent report of K. Arndt on electro-chemistry in the years 1916–18.[1] Before the War the German carbide industry utilised 20,000 h.p. from water power, and about 10,000 h.p. from coal, and its production amounted to 30,000 to 40,000 tons of carbide. The two oldest German carbide works are those at Rheinfelden and at Lechbruck in Allgäu, which latter has operated since 1900. The Bayrischen Stickstoffwerke A.G. utilise 32,000 h.p. at their main works at Trostberg and Tacherting on the Alz, producing 50,000 tons of carbide per year. Of the Imperial nitrogen factories erected under their supervision, by far the largest is the plant at Piesteritz (see p. 31) with a normal output of 10,000 tons of carbide per month, which is by far the largest of all carbide works. The only plant which is considerably larger is the enormous American plant at Muscle Shoals, with twelve carbide furnaces, each of which has an output capacity of about 50 tons per day. There are two carbide works at Rheinfelden which already existed before the War. One of these belongs to the Chem. Fabr. Griesheim-Elektron, and the other to the Aluminium-Industrie A.G., and they were originally erected simply in order to utilise the excess current from the electro-

[1] *Chem. Ind.*, 1914, Nos. 22/23.

lysis of alkali-chloride (up to 2,000 h.p.), and of aluminium manufacture (up to 5,000 h.p.). We have already discussed the carbide factories at Bromberg, Steinbusch and Waldshut in Baden; at Knapsack only about 10,000 h.p. were at first available; Lechbruck utilises 2,500 h.p., and Freyung vor dem Walde, near Passau, about 6,000 h.p. The Plesssche Bergverwaltung and the firm of Friedländer, which were later superseded by Beer, Sondheimer & Co., Frankfurt-a.-M., erected the "Elektroschmelzwerk Prinzengrube" at Lazisk in Upper Silesia for a production of 20,000 tons of carbide per annum. The Bosnischen Elektrizitäts A.G. erected a carbide works at Tschechnitz, near Breslau, adjoining the "Elektrizitätswerk Schlesien," and founded the Elektrochemischen Werke Breslau G.m.b.H. for its administration. The "Lonzawerk" erected a carbide works at Spremberg in Niederlausitz, and the Chem. Fabrik. v. Heyden-Radebeul of Dresden built another at Hirschfelde, near Zittau. The "Brandenburgischen Carbid-und Elektrizitätswerke" (see above) started a new plant for the production of carbide at Waldeck. The plans of the Dr. Alexander Wacker-Gesellschaft of Munich, which is developing power from a section of the river Alz, near Burghausen, are very extensive. At present production is confined to one carbide furnace, utilising 4,000 h.p., which are obtained in the form of current from the Salzach works or from Austria.

The diversion of the Alz into the Salzach and the production of 36,000 h.p. at the new Alz power station are contemplated. The development of Bavarian water power on large lines depends to some extent on the execution of the plans of the Imperial Treasury which have already been described. Smaller carbide works have also been erected at Wyhlen on the Rhine above Bâle, and at Horst on the Ruhr.

Remembering that the maximum German output of calcium cyanamide is about 600,000 tons per year of 20 per cent. quality, and that this would require about 480,000 tons of carbide, the estimated output capacity for carbide in 1918 of 400,000 to 450,000 tons appears to be too low; it should be about 550,000 tons. The production of nitro-lime for 1918, which was 300,000 tons, corresponds to at least 240,000 tons of carbide. Apart from this large internal production, considerable quantities have been imported each year from Switzerland and from Scandinavia. The large growth of the carbide industry is clear from the pre-war figures. Before the War Germany produced about 45,000 tons internally, imported about 60,000 tons, and utilised about 90,000 tons per annum. The extraordinary increase in the utilisation of

carbide is not due to the considerable increase in the production of nitro-lime alone, but also to the fact that carbide is used as a deoxidising agent in place of ferro-manganese in the iron and steel industry (German pats. 298,847, 300,012 and 300,764). The Deutsch-Luxemburgische Bergwerks und Hütten A.G. made over to the German steel works for the duration of the War, free of charge, a process of this character which had proved successful in the Thomas process. For this purpose the carbide is best remelted in an electric furnace and then added to the steel bath in liquid form. If the crude iron in the converter contains at least ·1 per cent. of manganese, carbide appears to render the addition of ferro-manganese unnecessary, and it is possible that this method of working will be continued permanently. Considerable quantities of carbide are also used for the production of acetylene, which finds important uses in connection with the autogenous welding of metal and also for illumination. The well-known production from acetylene of trichlorethylene and so forth was supplemented during the War by its conversion into acetaldehyde, acetic acid, alcohol, acetone, etc. The latter processes have become of great industrial importance, not only in Germany, but also in America and Switzerland. They are based on the work of Kuscheroff in 1884, who showed that acetylene could be converted into acetaldehyde with the intermediate production of mercury compounds. The possibility of producing alcohol or acetic acid by this method on an industrial scale was suggested at an early date by H. Erdmann, but was not carried into effect. The first patent applications on this subject by H. Wunderling appeared in 1908, namely, German patent applications W.27,177 and 29,233.[1] In February, 1910, N. Grünstein filed his German application G.31,034, which led to the grant of German pat. 250,356 of 1911, which was transferred to the Chem. Fabr. Griesheim-Elektron. The latter firm based their technical process on this patent, but met with considerable difficulties. Economically satisfactory solutions of the problem were discovered simultaneously, but quite independently, by the Consortium für Elektrochemische Industrie of Nürnberg (now of Munich), and the Höchster Farbwerke. Licences have been granted by the Consortium to the Dr. Alexander-Wacker-Gesellschaft of Burghausen on the Alz, and the Elektrizitätswerk Lonza. In 1916, both the Höchster Farbwerke and the Wacker-Gesellschaft succeeded in manufacturing acetic acid from carbide on a large scale in Knapsack and Burghausen, respectively. As has already been mentioned, the method of production was closely associated with the rubber synthesis of the

[1] See also Friedländer, "Fortschritte," vol 9, p. 15.

War period, which has been abandoned. The present German industry making acetic acid from carbide is stated to have a total output capacity of 25,000 tons of acetic acid per year. The output capacity for acetone of Knapsack and Burghausen was said to be 600 tons per month in 1918. This has never yet been attained. The German production and utilisation of carbide in 1918 was approximately as follows :—

240,000 tons for production of calcium cyanamide.
60,000 tons for the lighting industry, for metal working and in the iron industry.
25,000 tons for further conversion into alcohol, trichlorethylene, etc.

Total 325,000 tons.

A number of important data on alcohol and other products from carbide are given in Appendix X. to the Bill of 1918 on the Imperial Spirit Monopoly. Further details may be gathered from the memoranda and discussions relating to this law, from which the Höchster Farbwerke, according to their report for 1917, anticipated serious prejudice to their manufacture. For the production of 1,000 kg. or 1,262 litres of alcohol, there are necessary 2,000 kg. of carbide (or 8,000 k.w. hours, 2,500 kg. of coke, and 7,000 kg. of lime). Further, 500 cu. m. of hydrogen gas are required per ton of alcohol. The official memorandum estimates the production costs to be 24 marks per hectolitre, according to the prices ruling in 1917–18. According to the experience of the Lonza works at Visp, Switzerland, the purification of the resulting alcohol offers no greater difficulty than that of ordinary fermentation alcohol. Alcohol from carbide can replace ordinary fine industrial spirit without further treatment. According to official information, the output capacity of the plants which existed or were in course of construction in Germany in 1917–18 was approximately 450,000 tons of carbide when working to their full capacity. After deducting about 50,000 to 60,000 tons used for lighting purposes, for metal working, etc., there would presumably remain almost 400,000 tons for the production of fertilisers or alcohol from which one could obtain theoretically about 2,500,000 hectolitres of alcohol. In 1913–14, Germany produced 3,844,000 hectolitres of spirit (calculated as 100 per cent.), for the production of which the following quantities of raw material were used :—

2,600,000 tons of potatoes.
320,000 tons of grain (rye, maize, and barley).

57,800 tons of molasses.
327,000 hectolitres of stone-fruit.
176,000 hectolitres of grape residues and yeast.
48,000 hectolitres of grape-wine.
81,000 hectolitres of brewery residues.

In view of these figures, the economic value of alcohol from carbide for which the main requirements are lime, coke and electric energy, is evident. The view expressed in the official memorandum of the future co-operation of the carbide and cyanamide industries is of still greater interest to us here. It is as follows: "The question whether the 500,000 to 600,000 tons of fertiliser producible in the form of calcium cyanamide can readily be absorbed must depend, apart from prices, primarily on the question whether this product meets with competition from imported Chile and Norwegian nitrate or possibly from other technically more advantageous fertilisers. Should the anticipation prove correct that relatively cheaper nitrogenous fertilisers can be produced by the Haber process than is possible with the help of carbide, the question of new outlets for the large carbide and calcium cyanamide plants of Germany will necessarily arise." We thus meet here with a relatively pessimistic outlook, which may also be found between the lines of the report of the A.G. für Stickstoffdünger in Knapsack (p. 31). The realisation of the Imperial project of large scale development of the Bavarian water powers, followed by the transference of the whole nitro-lime manufacture to these localities, where cheaper power would be available, is, therefore, highly desirable. Unfortunately, the unsatisfactory financial position of the German Government renders such large plans impossible for the time being. As the provision of nitrogenous fertilisers is so intimately connected with the food supply of the German people, it must be considered as a primary requirement for the present, and, until it can be covered in other ways, as is for the time being impossible, it is most urgently necessary that the existing nitro-lime works should be maintained, even though they are at present situated in unsuitable localities. In the course of the paper which has already been mentioned on the electro-chemical industry, K. Arndt comes to the following conclusions regarding the manufacture of carbide and nitro-lime: "It is impossible to foresee the exact future of these plants in years to come. Those works which utilise water power will certainly continue to exist indefinitely, but those which use coal as a source of energy will in most cases cease to exist unless the usual interest on the very high erection costs is relinquished."

If, in place of hydrogen, electrolytically produced oxygen is used in presence of a catalyst, the acetaldehyde is converted into acetic acid. Before the War technical acetic acid was mainly produced in Germany from the grey acetate obtained in wood distillation, but dilute acetic acid (vinegar) was usually produced from alcohol, and so forth, by fermentation by the "rapid vinegar process." There are 20 works in Germany producing acetic acid from wood, the largest of which is the Verein für Chemische Industrie of Mayence. The annual imports previous to 1914 were about 20,000 tons of grey acetate, mainly from the United States, but also from Austria-Hungary. The domestic production was about 15,000 tons, so that in time of peace 35,000 tons of grey acetate, containing on an average 82 per cent. of calcium acetate, were annually used in Germany for the production of acetic acid, its derivatives and acetone. The fermentation acetic acid industry was conducted in about 1,000 small works; there were larger works, such as, for instance, Kahlbaum of Berlin; in 1913–14 this industry used 151,400 hectolitres of 100 per cent. pure alcohol, and also produced considerable quantities of table vinegar, beer, malt, and wine vinegar. On the other hand, according to official figures, the recent output capacity of the German plants for the production of acetic acid from carbide, including those still under erection, amounts to 25,000 tons of acetic acid per annum, as has already been mentioned. This quantity is more than twice as great as the alcohol corresponding to the imported grey acetate (20,000 tons of grey acetate containing 82 per cent. of acetate = 12,460 tons of pure acetic acid), so that it might become of great economic importance. Naturally the official memorandum could make no definite statements on the cost of production of acetic acid from carbide in Germany, or on the possibility of competition of the product with that from grey acetate. It is all the more difficult to form a final opinion on this question at present, as, in consequence of the confused economic circumstances, the effect of the Imperial spirit monopoly has not become apparent in practice on a large scale. According to an announcement in the daily Press (*Magdeburger Ztg.*, June 20th, 1920), Saxon industrialists have recently founded a new company in Belgern (Province of Saxony) with a capital of 12,000,000 marks for the manufacture of spirit from carbide. The initial daily production is to be 15,000 litres of spirit, and the works were to be ready in December, 1920. It was found later, however, that the parties had been victimised by an impostor, and the plan has fortunately come to nothing.

The use of acetylene as a motive power for internal combustion

engines (260 litres of acetylene, or 0·9 to 1 kg. carbide, are required per horse-power hour) can only be considered as a war measure, and is rapidly declining.

Having described the historical development and the economic basis of the German nitro-lime industry, and of those industries directly connected with it, we will now discuss the importance of the Haber synthesis of ammonia, which may claim to be a specifically German development of a technically highly developed scientific organisation and a brilliant example of the co-operation of theory and practice.

In 1903–4, Haber, jointly with Van Oordt, commenced the experimental study of the ammonia equilibrium at definite temperatures and pressures.[1] These investigations formed the foundation of the synthesis of ammonia which has since become so important, and which will be discussed in greater detail in the third part of this volume. In this section we are only interested in the historic and economic development of the Haber-Bosch process. The detailed treatise of F. Haber and R. Le Rossignol in the *Zeitsch. f. Elektrochemie*, 1913, vol. xix, p. 53, is a shortened summary of the report of the inventors to the Badische Anilin und Sodafabrik in the year 1909–10. The yield was by no means extraordinary, and there seemed to be little hope of a successful solution of the problem of technical ammonia production. In spite of this, the B.A.S.F. took the warmest interest in the work. The first patent applications (German pats. 223,408, 235,421, 238,450, etc.) date from the year 1908. The transformation of Haber's laboratory experiments into methods available for technical manufacture on a large scale met with inconceivable difficulties, and was largely due to the daring initiative of the B.A.S.F. and of its chemists, more particularly of Bosch and Mittasch.[2] As a result of the knowledge gained by the associated workers, F. Haber was enabled to give a paper before the Naturwissenschaftlicher Verein Karlsruhe on March 18th, 1910, in the course of which the new process was practically demonstrated for the first time. Although the foundations were thus laid, very much remained to be done before the technical manufacture by Haber's method could be successfully undertaken. The first synthetic ammonia was produced by the experimental plant at Ludwigshafen at the close of 1910; the output was 25 kg. of ammonia per day at the commencement of 1911, and 1,000 kg. per day in 1912. The process represented a revolution in technical chemical plant, as the conduct of processes at such high temperatures as 600° C. and at pressures of about 200 atmospheres had been hitherto unheard of.

[1] *Zeitsch. f. anorg. Chem.*, **43**, 111; **44**, 341; **47**, 42.
[2] See Bernthsen, *Chem. Ztg.*, **1912**, p. 1133.

As is well known, it is only under such conditions that a product containing about 10 per cent. of ammonia can be obtained from the equivalent mixture of nitrogen and hydrogen. As may be imagined, the mechanical difficulties were extraordinarily great. However, the manufacture in the experimental plant was so successful that the erection of a special works for the manufacture of ammonia at Oppau, close to Ludwigshafen, could be considered. These works were producing by the end of 1913. The main product was at first anhydrous liquid ammonia, but later ammonium sulphate was also produced and appeared on the market at the commencement of 1914. The Oppau works were intended for the manufacture of ammonium sulphate only, and, in the first instance, for a production of 30,000 tons per annum. Assuming approximately 300 working days in the year, this production corresponds to about 25 tons of ammonia per day, which corresponds in turn to 7,500 tons of ammonia or 6,180 tons of nitrogen or 30,000 tons of ammonium sulphate (containing 20·6 per cent. of nitrogen) per annum. C. Matignon states that he was informed that the cost price per ton of synthetic ammonia was 150 fr. = 121,50 marks (£6), or 48·6 pfg. per kilogram of ammonia—that is, 59·0 pfg. per kilogram of nitrogen.

In the autumn of 1913 the East German and Austro-Hungarian producers of ammonium sulphate met and decided to form a syndicate to be directed by the Oberschlesischen Kokswerke A.G., which, whilst maintaining the agreement which already existed with the Deutsche Ammoniakverkaufsvereinigung G.m.b.H. of Bochum, was to secure adequate markets for the ammonia produced by coke ovens and gas works in competition with the synthetic product. The intention was to lower the price to such an extent that the synthetic product, with its higher production cost, would be unable to compete. A comparison with the figures of the largest producers of the German Association for the Sale of Ammonia (Deutsche Ammoniakverkaufsvereinigung) shows how comparatively considerable the production of the Oppau Works was. The production of ammonium sulphate at various works in the year 1912–13 was as follows :—

	Tons.
Gelsenkirchen	30,827
Deutsch-Luxemburg	24,449
Harpen	22,513
Phönix	19,928
Hibernia	10,804
Ammoniak-Verkaufsvereinigung (total)	300,000
Upper Silesian Works	35,000
1912 German production	492,000
1913 German production	549,000

In the autumn of 1913 a union of the other producers with the B.A.S.F. seemed hardly possible. Meanwhile the latter concern, jointly with the other works of the coal-tar dyestuff industry, had commenced negotiations with the Verein Chem. Fabriken A.G., of Zeitz, which led, at the end of 1913, to the acquisition of the majority of the shares of the latter firm. The Zeitz Verein is a large consumer of ammonium sulphate, of which it marketed very large quantities before the war in the form of mixed fertilisers (ammonium superphosphate, etc.). Thus at one stroke the B.A.S.F. found a reliable large customer and at the same time assured the economic stability of the Oppau plant, in which several million marks had by that time been invested. As a direct consequence, the long-sought-for understanding between the B.A.S.F., on the one hand, and the Deutsche Ammoniakverkaufsvereinigung and Oberschlesische Kokswerke, on the other, was concluded at the commencement of 1914. The political conditions prevented any obvious effect of the conclusion of this price convention on the German fertiliser market, or on the world market, for since August, 1914, the nitrogen industry has worked under completely altered conditions. The connection between the B.A.S.F. and the Zeitzer Verein has meanwhile ceased, and this purely temporary alliance may therefore be considered as a mere tactical measure.

In order to ensure supplies for the explosives industry, the Oppau plant ceased producing ammonium sulphate, and turned to the production of the war materials, ammonium nitrate, synthetic nitrates, nitric acid, etc. By the close of 1915, the annual output capacity was already 130,000 tons of ammonium sulphate, equal to approximately 26,300 tons of nitrogen. The output capacity in 1917–18 is stated to have been as follows:—

	Tons per Annum.	Tons of Fixed Nitrogen.
Ammonium nitrate	10,000	3,450
Sodium nitrate	130,000	21,410
Nitric acid (calculated as 100 per cent. acid)	40,000	8,890
Anhydrous ammonia	40,000	32,900

Thus the peace-time output capacity had been increased more than tenfold. According to foreign sources, the output capacity of Oppau for 1918 was :—

Output per day : 250 tons of NH_3 = 206 tons of N, amounting in round figures to 66,650 tons of N in a year of 323 working days.

A portion of this ammonia was converted into nitric acid (250 tons of NH_3 = 926·5 tons of HNO_3).

The daily production of nitric acid, calculated as 100 per cent. acid, was 100 tons; meanwhile the output capacity has been increased to 200 tons of 100 per cent. nitric acid; the remaining ammonia, that is, about 115 tons of NH_3 daily, was supplied to Höchst.

Before considering the development which led to a further increase in the nitrogen works of the B.A.S.F., we will briefly consider the economics of the process compared with other processes, making use of the publications of R. E. McConnell, Chas. Parsons, C. Matignon and others. According to the calculations of Parsons, the manufacture of ammonia by the Haber-Bosch process involves works costs of $119 per ton of nitrogen (= 499·80 marks), that is, 41·3 pfg. per kilogram of ammonia. In order to fix this quantity of ammonia, about 4 kg. of sulphuric acid of 60° Bé. are necessary; taking the price of this to be 10 pfg., then from the prices for ammonia and sulphuric acid we obtain a cost price for the ingredients of ammonium sulphate of 132 marks (£6 12*s.*) per ton (apart from manufacturing costs). The agreement of this value with Matignon's figure (see above) of 150 fr. (= 121·50 marks) per ton of ammonium sulphate, is so close that Parsons' figure may be considered as correct at the time when his report was made, that is, on April 30th, 1917, and thus for the period 1916–17. According to Matignon's figures, the production cost of 1 kg. of ammonium sulphate by Haber's process is 12·15 pfg. For its manufacture there are required about 250 gm. of ammonia and 1 kg. of sulphuric acid of 60° Bé. If we assume the cost of this to be 2·5 pfg., and the cost of conversion of ammonia into ammonium sulphate under these conditions (see below) to be 1 to 2 pfg. per kilogram of ammonium sulphate, we obtain a works cost of Haber ammonia in peace-time of 30 to 35 pfg. per kilogram. The English Lieutenant R. E. McConnell, who inspected the Oppau plant during the truce, gives the following details in the *Journal of Industrial and Engineering Chemistry*: The plant employs 1,500 labourers, 3,000 mechanics, 350 clerical officials, and 300 chemists; it consumes daily 1,750 tons of lignite and 500 tons of coke, producing about 250 tons of ammonia, or 206 tons of fixed nitrogen. On the assumption that the works close for about one-tenth of the year for repairs, McConnell arrives at a cost price of 5½*d.* per lb. of fixed ammonia—that is, 103 pfg. per kilogram of nitrogen or 85·0 pfg. per kilogram NH_3. At the commencement of 1918, Haber ammonia was sold at works at 0·90 marks per kilogram of NH_3 in the form of concentrated ammonia liquor, exclusive of freight and of the surcharge of the Kriegschemikalien A.G.; McConnell's figure is therefore probably

not far from the truth. Thus the production costs per kilogram of NH_3 and of N by the Haber-Bosch process were as follows :—

	1 Kg. NH_3. Pfg.		1 Kg. N. Pfg.
1913–14	30 to 35	..	36·5 to 42·5
1916–17	41·3	..	50·2
1917–18	85·0	..	103·0

We may now compare these with the costs by other processes. Parsons calculates the price per kilogram of fixed nitrogen in calcium cyanamide to be $122 per ton of nitrogen—that is, 51·24 pfg. per kilogram. This figure corresponds roughly with German prewar conditions. The sale price at the close of 1913 was 114 pfg. per kilogram of nitrogen in calcium cyanamide. In the spring of 1918 the sale price had risen to 180 pfg., and the production costs to about 100 pfg.

With the help of the figures of the Jul. Pintsch A.G., of Berlin, Bertelsmann [1] gives the following calculations for a plant for the treatment of 10 cu. m. of standard gas liquor per twenty-four hours : he finds the production cost of 108 tons of ammonium sulphate to be 8,837 marks—of course, on the assumption that the gas liquor, from producer's own works, is a by-product, and therefore costs nothing, that is, it is merely debited with overhead charges.

He assumes that the costs are 286·6 pfg. per ton of steam, 1·60 marks per 100 kg. of lime, 4·50 marks per 100 kg. of 60° Bé. sulphuric acid, and 0·05 marks per cu. m. of water ; he also allows 4·50 marks for wages per shift. The consumption of steam per ton of ammonium sulphate is given as 2·77 tons, corresponding to 7·98 marks per ton of ammonium sulphate. Thus we obtain a production cost of 8·18 marks per 100 kg. of ammonium sulphate, or 32·73 pfg. per kilogram of NH_3, or 39·76 pfg. per kilogram of nitrogen under pre-war conditions. The conditions which exist in modern coke ovens are, of course, much more favourable. H. Koppers found that when waste steam was used in the distilling column the steam used for the direct process amounted to 0·225 tons per ton of ammonium sulphate produced. On the basis of this figure, and of a price of 2·50 marks per 100 kg. of 60° Bé. sulphuric acid, the cost price of 100 kg. of ammonium sulphate would be 5·45 marks, corresponding to 21·8 pfg. per kilogram of NH_3 or 26·5 pfg. per kilogram of N.

If we assume gas liquor to be treated by the direct sulphate process with ample utilisation of waste steam, we arrive at a cost price of 7·45 marks per 100 kg. of ammonium sulphate—that is, 29·8 pfg. per kilogram NH_3, and 36·2 pfg. per kilogram N. If the

[1] Ullmann, "Encyclopædia," vol. i., pp. 414 *et seq.*

Pintsch figures are recalculated for the prices ruling in 1917–18 (20 marks per ton of steam, 5 marks per 100 kg. of lime, 15 marks per 100 kg. of 60° Bé. sulphuric acid, 6 marks wages per shift, 10 pfg. per cu. m. of water, increased maintenance costs, etc.), we obtain the following figures : 11·25 marks per 100 kg. of ammonium sulphate, 45 pfg. per kilogram NH_3, and 54 pfg. per kilogram N. According to Pintsch's figures the pre-war costs of conversion of gas liquor into sulphate per kilogram of ammonium sulphate, and exclusive of the cost of sulphuric acid, were about 1·9 pfg. The average sale price in 1913 was 28 marks per 100 kg. of ammonium sulphate (that is, 1·12 marks per kilogram NH_3, and 1·36 marks per kilogram N). On March 1st, 1920, the official German maximum prices for 1 kg. of nitrogen were as follows :—

	Mks.
As ammonium sulphate, ordinary quality .	9·50
As ammonium sulphate, dried and ground .	9·85
As sodium nitrate	12·50
As calcium cyanamide	1·40

In addition there were transport charges amounting to 2·50 marks per kilogram of nitrogen in ammonium sulphate or sodium nitrate, and 9·30 marks in calcium cyanamide, so that the total costs per kilogram of nitrogen amount to 12 marks in ordinary ammonium sulphate, 10·70 marks in calcium cyanamide, and 15 marks in sodium nitrate.

The average price in Germany in 1913 of Chile nitrate containing 15·6 per cent. of nitrogen was 222 marks per ton, or 1·42 marks per kilogram of nitrogen. The price in England in 1920 was about 25*s.* per cwt. This price is the equivalent of 2·37 gold marks per kilogram of nitrogen, which at the exchange rate which was then in force (in June, 1920) corresponds to 26·16 marks per kilogram of nitrogen.

The various values are summarised in the following table :—

Production Costs in Pfennige

Process or Product	Year	1 kg NH_3	1 Kg N	Remarks.
Small scale production from gas liquor.	1913–14	32 73	39 76	100 kg. ammonium sulphate = 8·18 marks.
Production from gas liquor by the washing process.	1913–14	14·74	17·91	As concentrated ammoniacal liquor, per ton with 25 per cent. NH_3. (Market price = 205 marks.)
Production from gas liquor by the direct process on small scale.	1913–14	29·80	36 20	100 kg. ammonium sulphate = 7·45 marks.

Production Costs in Pfennige—continued.

Process or Product.	Year.	1 Kg. NH_3	1 Kg. N.	Remarks.
Production from coke ovens, direct process.	1913–14	21·80	26·50	100 kg. ammonium sulphate = 5·45 marks.
Production from gas liquor on small scale. Washing process.	1917–18	45·00	54·00	100 kg. ammonium sulphate = 11·25 marks.
Ammonium sulphate, German sale price.	1913	112·00	136·00	100 kg. ammonium sulphate = 28·00 marks.
Ammonium sulphate, German sale price.	1920	1458·08	1200·00	100 kg. ammonium sulphate = about 250·00 marks.
Haber ammonium sulphate.	1913–14	48·6	59·00	199 kg. ammonium sulphate = 12·15 marks.
Haber ammonia. . .	1913–14	30 to 35	36·5 to 42·5	Manufacture of ammonia.
Haber ammonia. . .	1916–17	41·3	50·2	Manufacture of ammonia.
Haber ammonia. . .	1917–18	About 85·1	About 103	Manufacture of ammonia.
Nitro - lime (Calcium cyanamide).	1913–14	-	51·25	—
Nitro - lime (Calcium cyanamide).	1917–18	—	About 100	—
Nitro-lime. Sale price.	1913–14	–	114	Carriage paid in Germany.
Nitro-lime. Sale price.	1917–18		180	—
Nitro-lime. Sale price.	1920	—	1070	—
Arc process. . .	1913–14	–	71·4 as HNO_3	According to American sources.
Chile nitrate. Purchase price in Germany.	1913–14	–	119 142 marks at German locality of consumption.	1 ton Chile nitrate = 185·10 marks free Hamburg.
Chile nitrate. Purchase price in Germany.	Middle of 1920	- -	2,680	Exchange rate £1 sterling = 160·00 marks.
Synthetic German sodium nitrate.	Middle of 1920	- -	1,500	Maximum sale price.

The above prices are in fair agreement with those given by H. Goldschmidt, which are as follows :—

1 kg. nitrogen in nitro-lime = 60 pfg. (pre-war price).

1 kg. nitrogen from Haber process = 65 pfg. (war price).

The average production cost of Haber ammonia per kilogram of nitrogen, according to the above table, is 64·2 pfg., being the average of 39·5, 50·2, and 103·0 pfg. According to Goldschmidt, the present price per kilogram of nitrogen in Chile nitrate is approximately 100 pfg.—that is, only 15·06 marks per 100 kg. of nitrate. I consider this price too low, and have therefore replaced it by 18·51 marks per 100 kg. of Chile nitrate, free Hamburg. Even this value is rather low. In the German home trade, Chile nitrate was sold before the

War at 10 to 11 marks per 50 kg. A similar figure, namely 222 marks per ton, was used by Ost in calculating the value of the total German imports of Chile nitrate in 1913. In England, in 1920, the price of Chile nitrate varied from 51*s*. to 53*s*. per 100 kg.—that is, from about 3·3 to 3·4 shillings per kilogram of nitrogen. In Antwerp it was offered at the end of April, 1920, at 145 fr. per 100 kg.—that is, 9·30 fr. per kilogram of nitrogen. According to Goldschmidt, the conversion cost of ammonia into ammonium sulphate is 5 pfg. per kilogram of nitrogen—that is, about 1 pfg. per kilogram of ammonium sulphate. In calculating Matignon's value for Haber ammonia, I have assumed the conversion costs to be 1 to 2 pfg. Pintsch assumes 1·9 pfg. conversion costs in his calculations.

When comparing the economic value of the two most important processes, the relative fertilising values of Haber ammonia sulphate and of nitro-lime must of course be compared, for it would be mistaken to compare the manufacturing cost of free ammonia with that of nitro-lime, as the former could not be used as a fertiliser as such, and as the ordinary commercial form in which it was used before the War as a fertiliser was exclusively that of ammonium sulphate. When compared in this way, we find that the production cost per kilogram of nitrogen in Haber ammonium sulphate in 1913–14 was slightly higher than that of the nitrogen in nitro-lime; in 1917–18, however, the cost price of nitrogen in the two products was approximately equal. The production cost of nitrogen from coal in the form of ammonium sulphate is without exception lower than that of the synthetic product, at any rate during the period covered by our table. As is known, these relations altered fundamentally later, so that to-day the commercial production of ammonium sulphate from by-product ammonia is often very difficult. This change is, however, mainly a consequence of the extraordinary rise in the price of sulphuric acid, and has little to do with the actual production of the nitrogen compound. The conclusion arrived at here, that the production cost of coke-oven ammonium sulphate is lower than that of the synthetic product of the B.A.S.F., is in agreement with the view taken by the Association of Producers of By-product Ammonia before concluding the sales convention with the B.A.S.F.

In order to manufacture ammonia and ammonium sulphate from nitro-lime, the latter compound has to be heated with water under pressure and the evolved ammonia led into sulphuric acid. Goldschmidt calculates the cost of these operations to be 30 pfg. per kilogram of nitrogen. This figure is too high for pre-war conditions. If this figure were used, the production costs per kilogram of nitrogen

in ammonium sulphate from nitro-lime during the year 1913–14 would be 81¼ pfg. This figure, although too high, shows clearly that although it was still possible to sell at a profit, the product which was obtained could not compare in any way with by-product or Haber ammonium sulphate.

The price of nitrogen in Chile nitrate at the locality of consumption in 1913–14 was 142 pfg. per kilogram, and thus considerably higher than in the above-mentioned products.

It is clear from the above that on account of the unfortunate position of the German sulphuric acid industry nitro-lime is the cheapest of the fertilisers produced within the boundaries of Germany. This statement must, however, be made with one reservation: nothing has so far become known of the commercial results of the gypsum ammonium sulphate process of the B.A.S.F., in which sulphuric acid is not used; the methods which have been developed of utilising the nitrogen and sulphur of coal for the production of ammonium sulphate still belong to the future to such an extent that a final opinion of the economic possibilities on the large scale cannot yet be formed. The conversion of nitro-lime into ammonia, and the further conversion of the latter into either ammonium sulphate, nitric acid or nitrates, is economically less favourable than the utilisation of by-product or Haber ammonia for this purpose, quite apart from the fact that it is economically unsound to destroy a finished fertiliser, namely, nitro-lime, in order to produce another more expensive fertiliser, namely, ammonium sulphate or nitrate, unless, indeed, there are very urgent reasons for the conversion, such as difficulties in selling the original product. The production cost of by-product ammonia, in so far as one may speak of a production cost of that which is essentially a by-product, will always remain lower than that of Haber ammonia. As the import of Chile nitrate into Germany on any scale must be considered as impossible for an indefinite period, on account of the cost, there is no reason to expect a fight in the German home market between nitro-lime and Haber ammonia, as has been prophesied in some quarters. Whilst the large scale industrial production of Haber ammonia depends on the energy of coal, that of nitro-lime depends on the development of water power. If only from the point of view of the general economics of the community, it is in the interests of the German coal reserves that the nitro-lime industry should be transferred to localities where cheap water power is available, as is indeed already planned. The further development of the Haber process should prevent the decomposition of nitro-lime for production of ammonia, as hitherto carried out, for reasons which have already been stated. It is clear

that in any case the best use of nitro-lime is as a fertiliser. Cheap new methods of converting it into other products would be a useful achievement. Whereas the manufacture of nitro-lime corresponds unconditionally to the urgent necessities of these times, in so far as it is produced from German raw materials only, this will not be the case with Haber ammonium sulphate until the gypsum process has been perfected or until a sufficient quantity of sulphuric acid is produced in Germany. The gypsum process was itself a complete success. Its general introduction was only prevented at first by the circumstances of the time. The production of sufficient pure sulphuric acid from internal resources is impossible, as insufficient quantities of pyrites are available. The production of sulphur or sulphuric acid from gypsum is so difficult (although in one month during the War 1,000 tons of SO_3 were obtained from $CaSO_4$ at Leverkusen), that the Deutsche Claus-Schwefel-G.m.b.H. in Bernburg, had to discontinue the process on account of the extraordinarily high working costs, as imported sulphur can be purchased much more cheaply than the German artificial product. The B.A.S.F. were therefore obliged to develop their gypsum process. Bearing in mind that the sulphuric acid radicle in ammonium sulphate clearly represents useless ballast (which may in certain circumstances be harmful by destroying the alkalinity of the soil by combining with lime, etc.), the attempts of the B.A.S.F. to prepare other suitable compounds from ammonia appear to be fully justified. The production of ammonium chloride is in no way an ideal solution of the problem, as the disadvantages attaching to the chloride radicle are exactly the same as in the case of the sulphuric radicle. At the same time, hydrochloric acid or chlorides, which can be used as raw materials, are domestically available in quantity, so that at least one economic requirement of Germany is thus met. The best solution of this problem is, on the one hand, the preparation of urea, urea derivatives, ammonium carbonate, and so forth, that is, of materials similar to those in stable manure—the primitive material used for the purpose—to which we now return by a complicated series of processes, or, on the other hand, the oxidation of ammonia to nitric acid followed by the manufacture of ammonium nitrate, synthetic nitrates and mixed fertilisers. These problems have, of course, to be faced, not only by the Haber ammonia process, but also by the manufacturers of by-product ammonia from coke ovens and gas works, who have also to cope with another similar problem—namely, the simultaneous utilisation of the sulphur contained in coal. The German coal production in 1913 was 191,000,000 tons. Assuming that the production of ammonia from this is, on the average,

0·2 per cent., this represents 382,000 tons of nitrogen, and, assuming an average sulphur content of 2 per cent., it represents 3·82 million tons of sulphur, equal to 5·85 million tons of sulphuric acid. These figures are, of course, of relative value only. They show, however, that the quantity of sulphur is amply sufficient to form ammonium sulphate with the ammonia which can be produced. In spite of various promising beginnings, associated with the names of Burkheiser, Feld and others, we are still far removed from success in this promising field.

According to Parsons, the arc process requires almost five times the amount of power per unit of fixed nitrogen required by the nitro-lime process, and its economic prospects in Germany are therefore in general unfavourable. It offers the advantages, however, that nitric acid is produced without the formation of ammonia as an intermediate product, and also that it uses air directly as a raw material. As will be explained later, it achieved relatively little importance in Germany during the War, for the reason that the cost of electric energy plays a main part. It will therefore only be able to maintain itself in future in localities where cheap water power is available, and therefore possibly in Upper Bavaria.

In the Haber-Bosch process, in connection with which the general question of the economics of nitrogen fixation has been just discussed, the value of the raw materials is greatly increased. At the German sale price of ammonium sulphate in 1913, 1 kg. of NH_3 represented a value of 112 pfg., whilst, according to one of the earliest publications of the B.A.S.F., the values of the raw materials necessary for its production are approximately as follows: 0·176 kg. of hydrogen = 1·96 cu. m. (value 17·5 pfg.), and 0·823 kg. of nitrogen = 0·66 cu. m. (value 2·5 pfg.). Incidentally, the latter price appears rather high.

Parsons, whose investigations on the various synthetic processes depend on reliable sources, emphasises the fact that the Haber-Bosch process is certainly the cheapest method of synthetic production of ammonia, as the total energy requirements are small, and it is therefore independent of cheap sources of power. On the other hand, the coal requirements are larger than those of the nitro-lime process. In agreement with the value given in the above table, Parsons mentions elsewhere a production cost of about 4 cents per pound, that is, about 33 pfg. per kilogram, of pure anhydrous liquid ammonia, under pre-war conditions. The plant required for the Haber-Bosch process is naturally rather sensitive, and requires frequent repairs and replacements, in spite of the large amount of technical skill bestowed on its design. In his calculations, Parsons

allows 20 per cent. of the installation cost for repairs, interest and wear and tear, as amortisation when considering the Haber-Bosch process, and McConnell, when discussing the Oppau Works, assumed that in a normal period such a plant would stand completely idle for at least one-tenth of the year for repairs, an assumption which is also made by Parsons. The rapid increase in production costs shown in the table is presumably accounted for by the increased costs of repairs during the working period, mainly due to war-time extensions and new war-time plant. In his book "Weltwirtschaftschemie" (1921), W. A. Dyes very severely criticises the German nitrogen industry, particularly that branch of it concerned with the production of nitro-lime (pp. 126, 587 *et seq.*).

The Oppau Works were extended by additional capital supplied by the Aniline Combine, for which purpose the firms of the old triple alliance increased their capital in 1915–16, B.A.S.F. and Fr. Bayer & Co. by 54,000,000 marks each, and Agfa by 19·8 million marks. In 1916 the extended Interessengemeinschaft was formed by the admission into the original combination of the second triple alliance (Höchster Farbwerke, Leopold Cassella & Co., Kalle & Co.), and also of Weiler-ter Meer, of Ürdingen: certain of the component firms, such as Höchst, increased their capital at the same time. The old aniline combination, including the B.A.S.F., on the one hand, reserved their rights appertaining to the Haber process, which were excluded from the general pool, and, on the other hand, the group which included Farbwerke Höchst similarly reserved their rights appertaining to the manufacture of nitro-lime, calcium carbide, acetic acid from carbide, and so forth. The Chem. Fabr. Griesheim-Elektron entered the enlarged I.G. in 1917, and also reserved to themselves special rights for certain of their products. The year 1917 was characterised by further large increases of capital, amounting to 36,000,000 marks each for the B.A.S.F., Leverkusen and Höchst (the capital of each being raised to 90,000,000 marks); 13·2 million marks for the Agfa, with a total capital of 33,000,000 marks; 9,000,000 marks for Griesheim, with a total capital of 25,000,000 marks; 15,000,000 marks for Leopold Cassella (now 45,000,000 marks); and 32·4 million marks for Weiler-ter Meer (now 10·4 million marks). These capital extensions were completely overshadowed by those which took place in 1919. These were undertaken partly in order to meet foreign competition, to cope with the depreciation of the currency, and also in order to provide the necessary means to complete the extensions of the nitrogen industry without participation by the Imperial Government, and to consolidate the enterprises at Oppau and Leuna, which had already

absorbed several hundred million marks of the I.G. The distribution of preference shares with increased voting rights was a measure directed against the introduction of foreign capital, which threatened to absorb a majority of the shares. The new distribution of ordinary shares led to the following relative share interest, and to 378·4 million marks of new capital, as shown in the following table, expressed in millions of marks :—

	Previous Capital.	New Ordinary Shares.	New Preference Shares.	Present total Capital.	Mortgages, 1916.
Höchst	90	90	72	252	8·74
B.A.S.F.	90	90	72	252	21·11
Leverkusen . . .	90	90	72	252	25·00
Agfa	33	33	26·4	92·4	7·82
Griesheim	25	20	18	63	4·88
Weiler-ter Meer . .	10·4	10·4	8·3	29·1	2·56
Kalle & Co. . . .	—	—	—	—	3·75
Leop. Cassella . .	45	45	36	126	10·00
Total	383·4	378·4	304·7	1066·5	83·86

Apart from the purely business aspect of this enormous capitalisation, the figures have also a psychological value. They represent the confidence of the German heavy chemical industry in the financial and technical success of the Haber-Bosch ammonia synthesis. On conclusion of the main capital transaction, the reserved rights within the I.G. were annulled. The old triple alliance of the B.A.S.F. surrendered their special rights to the Haber process as from January 1st, 1919, and the Höchst group surrendered their rights in connection with the manufacture of nitro-lime, etc., which had for some time become relatively less important than the Haber-Bosch process. The special Griesheim rights were only surrendered at the end of 1919. The increased capital requirements of the above-mentioned large firms were also met, apart from their increased share capitalisation, by means of debentures—for example, the 4½ per cent. debenture issue of the B.A.S.F. in 1919 of 50,000,000 marks. The firm of Leopold Cassella further increased their capital in 1920 by 68,000,000 marks, making a total of 194,000,000 marks.

The actual production of the Oppau Works in 1913 was 4,000 tons of nitrogen, corresponding to 20,000 tons of ammonium sulphate. It was to have been extended to 30,000 tons of nitrogen annual output capacity, corresponding to 150,000 tons of ammonium

sulphate. In consequence of the demand due to the War, which had broken out in the interval, the capacity was doubled, and was further increased at a later date. In 1918–19 the production at Oppau was about 70,000 tons (actually 66,700 tons) of fixed nitrogen. The total German production of Haber nitrogen for the calendar year 1917, is estimated to have been 100,000 tons of nitrogen. As the contribution of Leuna-Merseburg was at that time not very important, the main proportion of this production must be ascribed to Oppau. As already mentioned, the cost of construction of the Oppau Works, according to foreign sources, was £5,000,000 to £10,000,000, or $75,000,000, and there were 1,500 labourers, 3,000 artisans, 350 clerical officials, and 300 technical officials, including engineers, chemists, etc. The daily production of NH_3 was about 250 tons, and 1,750 tons of lignite and 500 tons of coke were used daily. After the completion of the extensions [1] planned for the end of 1919, Oppau will produce approximately 100,000 tons of fixed N per annum.

Although, therefore, the contribution of Haber ammonia from the B.A.S.F. towards the nitrogen requirements of Germany was already very considerable, amounting to 400,000 tons of nitrogen for the year 1916, deliveries were by no means sufficient to meet the requirements of the so-called Hindenburg programme of 1916. Plans were therefore considered for the erection of a large new works to produce ammonia by the Haber-Bosch process. A further extension of the Oppau plant would not have been suitable, for military reasons, for Oppau was essentially within the zone of action of enemy aircraft, by which it was repeatedly attacked with more or less success in spite of energetic measures of defence. Although during such periods of serious danger the nitro-lime works could serve as suppliers of nitrogen for munitions, the general welfare was little served by such diversion, on account of the consequent diminution of nitro-lime supplies to the agricultural industry. The determination to erect an effective plant for the production of Haber-Bosch ammonia in the centre of Germany, utilising for the purpose the exceptionally cheap Central German lignite, was further fortified by the fact that in spite of the enormous demands of the munition industry, it was decided that further nitrogenous fertilisers must be supplied at all costs to agriculture, which absorbed 100,000 tons of fixed nitrogen for the harvest of 1916–17, this being about 50 per cent. more than the peace-time requirements in 1913, or 100 per cent. more than the requirements of 1909. Meanwhile Oppau had

[1] Retarded by the catastrophe of 1921, which involved the I.G. in considerable further capital requirements.

practically ceased to manufacture ammonium sulphate; for the year 1916–17, the main products are stated to have been ammonium nitrate, sodium nitrate, nitric acid and liquid ammonia. There was also a better opportunity in Central Germany of avoiding the use of sulphuric acid, which was very scarce, by utilising the very large deposits of gypsum in the South Harz for the manufacture of ammonium sulphate. At the end of May, 1916, the B.A.S.F. decided to erect a large new nitrogen works close to Merseburg-Corbetha (near Halle-a.-S.) on a property measuring about 6 × 1 km. For the erection of this plant several hundred million marks were advanced by the Imperial Government, which were to be repaid with interest in the form of a proportion of the production beyond a definite yearly minimum. In order to ensure supplies of lignite for the enormous new works, the B.A.S.F. acquired not only the lands and rights of the Wallendorfer Kohlenwerke, but also a completely equipped colliery, Dörstewitz-Rattmannsdorfer Braunkohlen A G., by acquiring the whole of their share capital at a very high figure (Wallendorfer, 400 per cent., and Dörstewitz-Rattmannsdorfer, 300 per cent.). The latter enterprise had never been able to show a profit, in spite of having existed many years, so that in this case, as in that of the Wallendorfer pit (20,000,000 marks for 5,000,000 marks share capital), the consideration seems to have been very high. The new works, "Leuna-Werk," or "Ammoniakwerk Merseburg," was first intended to fix 30,000 tons of nitrogen, then a further 100,000 tons, and, finally, a further 70,000 tons—that is, a total of 200,000 tons of nitrogen per year. The erection was so rapid that ammonia was already being produced in the early summer of 1917. By the acquisition of gypsum quarries at Niedersachswerfen, on the southern border of the Harz, not far from Nordhausen, a supply of gypsum for the manufacture of ammonium sulphate was assured. In 1918 the average daily output at Leuna was 400 tons of NH_3, or about 330 tons of fixed nitrogen, corresponding to about 110,000 tons of nitrogen per year.

The change in the military position of Germany and the political upheaval in the late autumn of 1918 had the most serious effect on the activities of the nitrogen industry. Oppau ceased production in consequence of lack of coal from the end of November, 1918, until June, 1919, and after December, 1918, the production at Merseburg-Leuna was disturbed, and repeatedly interrupted by strikes and by lack of coal. The conditions of production only improved very slowly. At the end of May, 1919, Leuna produced 200 tons of nitrogen daily in the form of concentrated ammonia liquor, but the complete utilisation of the plant was partly prevented by manu-

facturing difficulties among its large consumers (Agfa, Höchst, Griesheim, Piesteritz, etc.). The gypsum ammonium sulphate plant had at first to contend with manufacturing difficulties before regular working became possible. The production was about 50 tons per day at the commencement of May, 1919, and 200 tons per day in July, 1919, but it is intended that it should be increased to about 1,000 tons of sulphate per day, equal to 30,000 tons of sulphate per month, equivalent to 6,000 tons of nitrogen. Broadly speaking, the production of fixed nitrogen in 1919 was very small in comparison with the actual output capacity for reasons unconnected with the plant. In spite of the fact that the explosive industry no longer existed, only 54,400 tons of nitrogen could be delivered to German agriculturalists from May 1st, 1918, to October 31st, 1919, compared with 92,334 tons of nitrogen from May 1st, 1917, to April 30th, 1918.

After the complete extension of the works at Merseburg in 1921, Oppau and Leuna could together produce 300,000 tons of nitrogen per year ; the previous total output capacity was about 200,000 tons per year. Over 1,000,000,000 marks has been invested in these two nitrogen fixation plants.

There were employed at Leuna early in 1921 about 10,000 labourers and about 10,000 building operatives. The industrialisation of the Merseburg district has been greatly aided by the erection of the Leuna Works. The numbers employed in the lignite works of the Geiseltal were 2,464 in 1914 and 12,860 in 1920. At the close of 1920 the ammonia works at Oppau and Leuna were removed from the control of the B.A.S.F. and I.G., and now form a new independent limited company, with 500,000,000 marks capital, domiciled at Ludwigshafen. Shares have been taken up by the eight firms of the I.G. in the proportion of their share capital; the B.A.S.F. control, for example, 125,095,000 marks of ordinary shares, according to the proceedings of the extraordinary general meeting at Mannheim on November 27th, 1920. The foreign patent rights, and the Haber-Bosch process, have not become the property of the new company, but remain, as before, reserved by the old I.G. (Ludwigshafen-Leverkusen-Treptow). The Knapsack plant is also excluded from the new limited company. The Merseburg lignite interests are, however, included to some extent. The production at Leuna is to be increased and maintained at 200,000 tons of nitrogen per annum, and that at Oppau to 100,000 tons. The Aniline Combine is to be continued until December 31st, 1999.

The close interconnection between Höchst and the B.A.S.F. is also indicated by the fact that Höchst is interested to the extent of 2·81 million marks in the Elise II. pit, which was acquired by the

B.A.S.F. in 1916 from the Werschen-Weissenfelser Braunkohlen A.G. for 9,000,000 to 10,000,000 marks. Apart from the extension of ammonium sulphate production at Oppau and Leuna, the B.A.S.F. is concerned with the production of ammonia oxidation products in Oppau and other works of the I.G., and of many different kinds of mixed fertilisers, such as potassium ammonium nitrate, ammonium sulpho-nitrate, ammonium chloride, urea derivatives, and other substances. In order to overcome the objection of agriculturalists to the new fertilisers, the B.A.S.F. founded several agricultural advisory stations in 1920.

Various communications in foreign journals are of interest in forming an opinion of the Haber-Bosch process. A French Commission report that they were told when inspecting the Oppau plant that: "If they saw the plant they would not be able to reproduce it, and even if they erected it, they would not be able to work it." R. E. McConnell and E. C. Worden also acknowledge the superiority of the German Haber-Bosch process. The chairman of the English Nitrogen Products and Carbide Company states that it is improbable that the process will be worked to any extent outside Germany, that the working of the expensive and complicated plant requires very high technical ability, and that the process will also be very much influenced by fluctuations in the price of coal. The American process of the General Chemical Company, which was to have been worked on similar principles, was a fiasco, and the prospects of the French Claude process cannot, at present, be considered to be particularly favourable.

In common with the coke-oven and coal-gas by-product industry, the cyanamide and Haber-Bosch processes yield ammonia, but no nitric acid. When, therefore, on the outbreak of war, the demand for nitric acid and nitrate suddenly increased, the necessity arose of manufacturing nitric acid synthetically. As the cost of power appeared to render the development of the direct process of burning atmospheric nitrogen impracticable in Germany, attention was entirely directed to the oxidation of ammonia. No large scale industrial experience existed in this field, for in the whole of Germany there was only one unimportant plant—at the Lothringen Colliery near Gerthe in Westphalia—where ammonia was oxidised. In pre-war Germany, which was entirely unprepared for warlike operations, no connection existed between the War Ministry or the Department of the Quartermaster-General and the modest beginnings of the nitrogen industry. As a matter of fact, the very names of the Oppau and Gerthe plants were quite unknown to the authorities. The whole industry had, therefore, to be remodelled in order to cope

with the steadily increasing requirements of the military authorities.

The first work published on the oxidation of ammonia to nitric acid with a platinum catalyst was that of the Alsatian, Kuhlmann, in 1839.[1] These results were followed up further by W. Ostwald in Leipzig, and were first reproduced on a technical scale on the Königswusterhausen property of the Zentralstelle für Wissenschaftlich-technische Untersuchungen, Neubabelsberg. In 1905–6 the Directorate of the Lothringen Colliery at Gerthe, near Bochum, Westphalia, co-operated with W. Ostwald in order experimentally to apply the oxidation process to their by-product ammonia. The first industrial plant was erected at Gerthe in 1908. Meanwhile W. Ostwald developed his process further, jointly with E. Brauer. The patents which he applied for in France, England, Switzerland, America, and other countries, were granted, but a German patent was refused to him on account of the publications of Kuhlmann. The Ostwald process was therefore worked in Germany as a secret process. In 1910, the works were removed to Vilvorde, in Belgium, where manufacture by the process commenced in 1912. Ostwald and Brauer also erected an experimental plant for the Chemische Fabrik Griesheim-Elektron. Details of the laboratory process were also supplied to the Höchster Farbwerke. Detailed technical data, with all constructional details, were also communicated to the Berlin Anhaltische Maschinenbau A.G., a representative of which firm watched the working of the process at Gerthe for several days. Certain communications were also made to interested persons in France and in the United States, who inspected the Gerthe plant during erection and when at work. Neither Ostwald nor Brauer took any part in the large scale development of the oxidation process during the War. The English Nitrogen Products and Carbide Company acquired the Ostwald process before the War for 7·39 million marks (£369,500).

The refusal to employ the process which was encountered in time of peace, in spite of all attempts to introduce it, was mainly due to the very small difference in price which then existed between nitrogen in the forms of ammonia and of nitric acid. The only concern in Germany which found a basis for financing a new plant was at that time the Gewerkschaft Zeche Lothringen, by using their own by-product ammonia. In spite of many publications and suggestions by W. Ostwald [2] before the War, the fact that other considerations,

[1] *Ann. de chimie*, **29**, 281 (1839).

[2] *E.g.*, *Zeitsch. d. Ver. deutsch. Ing.*, 1903; *Chem. Ztg.*, 1903, p. 457; *Berg u. Hüttenmänn Rundschau*, **3**, 71 (1906); *Schwäbischer Merkur*, 1908; see also Schmidt und Böcker, *Berichte*, 1906, p. 1366.

such as those of national defence, might render the development of this extremely important process desirable, was not generally recognised by the official and technical authorities concerned. The process was also tried by the Erzherzoglich Friedrichschen Werke in Austrian Silesia.

The credit of having first called attention to the difficulties of supplying the demand for nitrate during the War belongs to the late Prof. E. Fischer, of Berlin. He first drew the attention of official Germany to the existence of the Gerthe plant, of which he had only heard by accident, according to a communication of Director P. Hilgenstock, of the Gewerkschaft Lothringen, of September 28th, 1914. It was at his instigation that the Government entered into close contact with the Lothringen Colliery, as neither the General Staff nor the War Ministry nor the Quartermaster-General had previously attached to this question the really vital importance to which it was entitled. Very little importance was attached in Germany to industrial war measures, either in this or in other directions, on account of the conviction that the War would very quickly be over. As already indicated, the first suggestions were for the erection of enormous plants for the production of calcium nitrate by the arc process. This plan was only dropped through the opposition of the experts, who pointed out the impossibility of the necessary supply of power, and also the technical and constructional difficulties. A further object at the time was also the adaptation of the first oxidation plants for the production of highly concentrated nitric acid. The Lothringen Colliery seriously criticised this plan, and recommended the much more reliable method of preparing synthetic nitrate and ammonium nitrate, which proved excellent in practice.

At first the Gerthe plant treated only 25 tons of ammonia gas per month, from which it produced 150 tons of nitric acid of 36° Bé. (52·8 per cent. HNO_3), corresponding to an average yield of 83 per cent. In association with the Lothringen Colliery, the German Government formed during the War a limited company called Chemische Werke Lothringen G.m.b.H. at Gerthe, Westphalia. The Government subscribed one-half of the capital of 10,000,000 marks, and also made several loans to the company. At the end of 1917 the Gerthe Works already treated 40 tank waggons per day of ammonia liquor from the coke ovens, containing 16 to 18 per cent. NH_3 (= 100 tons NH_3), from which it produced about 160 tons of synthetic calcium nitrate and 100 tons of ammonium nitrate. These figures show a total yield on the nitrogen of about 74·6 per cent. In 1920–21 the Lothringen Colliery was converted into a joint stock

company with a capital of 75,000,000 marks, as its previous organisation was unsuitable for so large an undertaking. The conversion was effected by converting the company "Bergbau A.G. Mark," whose shares were entirely in the possession of the Lothringen Colliery, into the Bergbau A.G. Lothringen on January 1st, 1921. As from that date, the Bergbau A.G. Lothringen, the firm of Henschel & Sohn of Cassel, and the Essener Steinkohlen-Bergwerke A.G., entered into an agreement for fifty years, which was to lead to a subsequent amalgamation. The registered office of the "Henschel-Lothringen-Steinkohlen-Vereinigung" was at Bochum. The Lothringen Colliery produced 652,375 tons of coal in 1919, and 826,106 tons in 1920, and also produced 237,596 and 264,242 tons of coke respectively in the same two years (Report of the Extraordinary Meeting of the Company in 1921).

Ostwald and Brauer used contacts of platinum foil, and K. Kaiser first suggested the use of platinum gauze. In 1912 he erected an experimental plant at Spandau, where he worked with admixture with hot air. The high yields which were first recorded, some of which exceeded 100 per cent., were finally found to be due to analytical errors. The process, which is described in German Patent 271,517, and was repeatedly shown to English, French and American interests in 1912–13, was unable to obtain further support. According to analytical figures. Kaiser obtained a yield of 95 to 97 per cent. of the theoretical in the contact unit.

Platinum was too difficult to obtain and far too dear to be used in large-scale war plants for the conversion of ammonia into nitric acid. The B.A.S.F. therefore repeated the older experiments, using iron oxide as a contact material. The Elberfelder Farbenfabriken [1] had already carried out investigations on similar lines (see German pat. 168,272; French pat. 335,229), as had also D. Meneghinis and others.[2] The process of the B.A.S.F. is characterised by an admixture of bismuth oxide; it enables better yields to be obtained, and therefore constitutes a great improvement. It had already been tried on a small scale before the War. Large scale technical experiments were commenced in September, 1914 and led to the erection of works in the spring of 1915. The Oppau Works were the first to take up the new process, and in 1918 they could produce 100 tons of (100 per cent.) nitric acid daily by this process. The output capacity of the Oppau plant at the end of the War is stated to have been 200 tons of nitric acid daily.

Shortly after the commencement of the War, the Frank-Caro

[1] *Chem. Ztg.*, 1904, p. 531.
[2] *Ibid*,, 1913, Repert , p. 378.

group also became interested in the oxidation of ammonia. Frank and Caro had claimed the use of the rare earth oxides, especially cerium and thorium oxides, as catalysts, in their German pat. 224,329; they now turned to the use of platinum contacts. I will quote Charles L. Parsons [1] with regard to the first negotiations :—

"They gathered together near Berlin some of the best chemical engineers of Germany and of the Scandinavian countries. Fortunately, W. S. Landis, a representative of the American Cyanamide Company, was also present. He obtained much important information and secured autoclaves and other machinery which, in spite of great difficulties, he succeeded in bringing to this country (U.S.A.). During the early part of 1915 he installed these autoclaves in an American munitions plant."

The Frank-Caro group used platinum gauze. The plant for this process was erected by the Berlin-Anhaltischen Maschinenbau A.G. (Bamag), of Berlin, which had already co-operated with the Lothringen Colliery in the development of the Ostwald process. By the end of 1915 the Bamag had either erected, or was erecting, 30 plants with a total output capacity of more than 100,000 tons of nitric acid; according to Parsons the condition of these in 1915 was as follows :—

Completed plant, yearly output capacity, 12,000,000 kg. NH_3.
Projected plant, yearly output capacity, 17,000,000 kg. NH_3.

The Frank-Caro-Bamag process was first developed in quite small units in sulphuric acid works (for use in the lead chambers), before being transferred to the actual nitrogen industry. Schuphaus [2] gave such detailed information, accompanied by exact drawings, that foreign interests became fully conversant with all details for the process, and were unable to understand how the German censors had passed the information. "It is hard to conceive how the German Government could have allowed the publication of this article."

The Farbenfabriken, Fr. Bayer & Co., in Leverkusen, used the iron-contact process. They produced 6,000 to 7,000 tons of synthetic nitrate, and 1,000 to 1,500 tons of nitric acid, of 40 to 47 per cent., monthly. The Farbwerke vorm. Meister Lucius & Brüning, in Höchst, used a platinum contact, and produced up to 8,000 tons of nitric acid monthly, calculated as 100 per cent. acid. The Höchster Farbwerke developed their process at Gersthofen on a large scale on the basis of Ostwald's experiments. The A.G. für Anilinfabrikation at Berlin-Treptow and Bitterfeld-Wolfen used iron oxide contacts, but

[1] *J. Ind. Chem.*, **11**, No. 6, June 1st, 1919, pp. 541–552.
[2] *Metall. und Erz.* [2] **13,** 22 (1916).

the Chem. Fabrik Griesheim-Elektron, who had also previously worked in conjunction with Ostwald, used platinum contacts. The Manfried oxidiser of Siegfried Barth, Düsseldorf, represents an entirely new development. Of the various contact masses which have been proposed, platinum and iron oxide alone have so far proved satisfactory in practice.

The condensation of the dilute nitrous gases is a very important problem in connection with the ammonia oxidation process, the difficulties of which for some time appeared to threaten its future, and are still greater in the case of the arc process.

All arc processes are based on the old observation of Cavendish, 1781–84, that when electric sparks are passed through air, nitric acid or nitrogen oxides are produced. A. Neuburger [1] has made an important contribution to the early history of these processes. The credit for having first thought of a technical utilisation of Cavendish's observations belongs to Madame Lefebre, of Paris, who in the year 1859 applied for an English patent, No. 1045, for the "Manufacture of Nitric Acid," which was in advance of the spirit of her time. Madame Lefebre used an apparatus which was similar to that of Muthmann and Hofer [2]; she recognised that admixture of oxygen was advantageous. Her patent specification includes a plan of a manufacturing plant, which naturally could not be developed at that time, as electro-technology was still in its infancy; but it remains interesting in the sense of Ben Akiba, as it already indicated the direction in which a successful solution of the problem lies. The first technical plant was that of the Atmospheric Products Company, in Jersey City, N.Y., which was erected according to the proposals of Bradley and Lovejoy, in 1902, but soon ceased manufacture. The work of the Norwegian inventors, Birkeland and Eyde, who had studied the question since 1903, met with more success. O. N. Witt has contributed a valuable paper [3] on the process, which proved so successful at the experimental plant at Ankerlökken, near Christiania, and at the subsequent larger experimental works at Vasmoen, near Arendal, that large-scale manufacture was commenced at Notodden on May 2nd, 1905. The Rjukan Works were added later.

Meanwhile the large German firms had also interested themselves in the nitric acid problem. The experiments of the B.A.S.F. were started in the nineties of last century at the instigation of their far-seeing director, H. v. Brunck, and in the course of these, Schönherr [4]

[1] *Zeitsch. f. angew. Chem.*, 1905, p. 1850.
[2] *Berichte*, **36**, 438 (1903).
[3] *Chem. Ind.*, 1905, pp. 699–707.
[4] *Elektrotechn. Zeitsch.*, 1909, Heft 16 and 17.

invented his process in 1905; this was first tried at Ludwigshafen, using 300 k.w., and then at the larger experimental works at Kristianssand, in the south of Norway, using 1,300 k.w. Manufacture was started at Kristianssand in the autumn of 1907. At the end of 1906 an agreement was already made between the Norsk Hydro-elektrisk Kvaelstof-Aktieselskab, which worked the Birkeland-Eyde process at Notodden, and the I.G., represented by the B.A.S.F. The I.G. at that time included the three largest dyestuff manufacturers, namely, the B.A.S.F., Bayer & Co., of Leverkusen, and Agfa. The Rjukan Works were to be built by these parties conjointly, and were to use both the Birkeland-Eyde and the Schönherr processes. The share capital of the nitrogen works was 18,000,000 kr., and that of the power company 16,000,000 kr.; a French-Norwegian group were responsible for half of this sum, and for the other half the combination of the German nitrogen factories in the proportion of their interests, namely, 43 : 43 : 14. These Norwegian holdings declined in importance on account of the development of the Haber-Bosch ammonia synthesis. In 1912 the I.G. cancelled the agreements, and the Norwegian interests were almost completely liquidated.

Whilst the processes of the Freiburg physicist Kowalski and his fellow-worker, Moscicki, acquired no importance in Germany, the Pauling process found considerable application. The first plant according to this system was built by the Salpetersäure Industrie-G.m.b.H. Gelsenkirchen, at Patsch, near Innsbruck, and has now been leased to the Elektrochemische Industrie G.m.b.H., of Cologne. The financial interests in these various companies have been united to form the Internationale Stickstoff A.G., of Wiesbaden, which is concerned with the development of the Pauling process. The plant at Patsch worked favourably, but the Internationale Stickstoff A.G., which had a capital of 2,068,000 marks, showed increasing deficits, although 932,301 marks were written off in 1915, and 986,900 marks in 1917. The company paid no dividends in 1919–20, and has ceased to be interested in the Elektrochemische G.m.b.H. of Cologne.

A Pauling installation was laid down at the railway power station at Muldenstein, near Bitterfeld, Province Saxony, in order to equalise the power load, but only worked for a short time, and was then closed down—it is said on account of the working costs being too high. A new Pauling plant is to be built in Upper Bavaria (see below).

In order to cope with the shortage of nitric acid in Germany during the War, the Allgemeine Elektrizitäts-Gesellschaft (A.E.G.)

and the Chem. Fabr. Griesheim-Elektron formed two companies in 1915, namely, the Elektrosalpeterwerke A.G., of Berlin, and the Elektro-Nitrum A.G., of Rhina-i.-B., each with 3,000,000 marks capital. The first company was first located at Zschornewitz and Gräfenhainichen, near Bitterfeld. The works were at Zschornewitz, and received their current from the Elektrowerke A.G. (Berlin) Zschornewitz-Golpa, which, until 1914–15 belonged to the firm Braunkohlenwerk Golpa-Jessnitz. This power station was to supply 240,000,000 k.w.h. per annum, and also supplied the Piesteritz Works and the towns of Berlin, Leipzig and Magdeburg. Current was first delivered to the nitric acid works in September, 1916. In the business year 1916–17, these works already absorbed 53,382,708 k.w.h. The works were completely destroyed by a serious explosion at about 9 p.m., June 18th, 1917, and have not since been rebuilt. On the other hand, the Elektro-Nitrum A.G., at Rhina-i.-B., on the Murg, near Säckingen, is still working smoothly by the same process, the Siebert process, in which the nitrogen oxides are directly liquefied. The gross working profit was 2,076,646 marks in 1917, and 2,620,968 marks in 1918; after writing off 1,432,951 marks in 1917, and 1,293,926 marks in 1918, the nett loss for the two years was reduced to 413,128 marks, and 569,987 marks respectively.

At Patsch 15,000 h.p. are available, of which only 6,000 were at first used; it was intended that 15,000 k.w. should be used at Muldenstein, which was intended to produce 6,000 tons of 50 per cent. nitric acid per annum, and at Rhina, as formerly at Zschornewitz, the power supply may now be about 30,000 k.w. From these figures it will be clear how very unimportant the arc process is in Germany compared with other processes, particularly as at present the Rhina plant is alone working, and utilises 30,000 k.w. = 40,800 h.p. Even when the yields are very good, an arc plant utilises about 2·33 h.p. years per ton of 35 per cent. nitric acid, and therefore the total German production of arc nitric acid cannot be much more than 17,500 tons of 35 per cent. nitric acid per annum, corresponding to 6,125 tons of 100 per cent. nitric acid, or 1,361 tons of nitrogen. According to Chas. L. Parsons, the amount of power required per ton of nitrogen in the form of 96 per cent. nitric acid is 10·8 h.p. by the arc process, and only 2·3 h.p. by the calcium cyanamide process, or 0·3 h.p. by the Haber-Bosch process, including the power required for oxidation. Thus the amount of power required for the arc process is so high that this method can only compete in Germany under quite exceptional circumstances—for example, where cheap water power is available. Moreover, the primary product must be combined with some base before it can be marketed as a fertiliser, which is the only

possible outlet in Germany at the present time on a large scale. Apart from the production of calcium nitrate or Norway saltpetre the only possibility is saturation with ammonia to form ammonium nitrate, or similar mixed fertilisers, as the production of synthetic sodium nitrate from sodium carbonate is economically impossible. The advantage of ammonia oxidation is all the greater, as the coke-oven industry and the Haber-Bosch process can supply large quantities of cheap raw material. Where large quantities of this latter product are available, as in Germany and the United States, the arc process is not likely ever to attain large dimensions. In such countries the question, which was still debatable in 1912–13, as to which method of producing synthetic nitric acid is the cheapest, has been definitely decided in favour of the ammonia oxidation process. In countries which are less developed industrially, and where coal is scarce, but where water power and other sources of cheap electric energy, such as natural gas, are available, the arc and nitro-lime processes are indicated. Parsons calculated that before the War the manufacturing cost per kilogram of fixed nitrogen was 71·4 pfg. by the arc process, about 40 pfg. by the Haber process, and about 51·25 pfg. by the nitro-lime process, basing these calculations on 420 marks per horse-power for the power plant, and 42 marks per horse-power year for the power. Though the actual production cost of dilute nitric acid by the arc process is low, this fact is more than balanced by the difficulties of concentration, of transport, or conversion into some suitable form for transport, and finally by the large power requirements.

Among other methods of nitrogen fixation, the method of F. Häusser deserves particular attention (see more particularly O. Dobbelstein, "Glückauf," 1912, pp. 289–300). Häusser obtains nitrogen oxides by explosion of gaseous mixtures. The process was evolved at the Nurnberg Works of the Maschinenfabrik Augsburg-Nürnberg, and was then transferred, with the co-operation of de Wendel & Co., Hayingen, from the Deutsche Stickstoff G.m.b.H., of Dortmund, to the Stickstoffwerke A.G., Herringen, near Hamm. These companies were under Government control during the War. They showed a deficit of 396,157 marks at the end of March, 1917, and in 1918 obtained permission to reduce their share capital from 1,000,000 marks to 200,000 marks, and again to increase their capital by 300,000 marks, or to liquidate the company. As nothing further has been heard with regard to the results, it may be concluded that the process has not yet achieved commercial success. It remains, however, historically interesting, as the only one of this group which has received industrial attention.

A similar fate awaited the Serpek process, which produces aluminium nitride from aluminium oxide, coal and atmospheric nitrogen. The first Serpek plant was erected in 1909 by the Internationale Nitridgesellschaft Zürich, at Niedermorschweiler, near Mülhausen (Alsace). This firm was later absorbed by the Société Générale des Nitrures, of Paris, which combined with the B.A.S.F., which was working on the same lines at that time, in order to avoid litigation by pooling all patent rights. The German interests in this interesting process were thus annulled. The experiments, which were mainly concerned with the construction of a suitable furnace, do not appear as yet to have come to a satisfactory conclusion.

Although the ammonia obtained by the dry distillation of coal cannot be described as synthetic ammonia, we will devote a few remarks to this process in consequence of its great economic importance, and as the ammonia obtained in this manner serves as a raw material for the oxidation processes.

The only original sources of ammonia were bones and urine. These relatively primitive methods of manufacture were superseded more than sixty years ago by the production of ammonia as a by-product in the distillation of coal. Coal contains on the average 1·0 to 1·6 per cent. of nitrogen, according to the origin of the coal. Karl Th. Volkmann [1] gives the following nitrogen percentages for coals of various origin :-

	Per cent. N.
Westphalia	1·50
England	1·45
Silesia	1·37
Bohemia	1·36
Saxony	1·20
Saar	1·06
Lignite	0·52

When coal is distilled in coke ovens or gas retorts, one-fifth to one-eighth of the nitrogen is recovered in the form of ammonia; the remainder either remains in the coke (from which it may be partially recovered by treatment with steam), distils in the form of prussic acid or organic compounds, or is lost in the form of free nitrogen, if the temperature is high enough to cause appreciable dissociation of the ammonia which is produced. The age of the coal and the method of heating have a considerable influence on the yield of ammonia. The presence of lime and more particularly of steam are favourable. The main portion of the ammonia is evolved between 500° and 700° C., and is very slight below 350° to 450° C. Bertels-

[1] "Chemische Technologie des Leuchtgases," Leipzig, 1915, pp. 49 *et seq.*

mann [1] refers to experiments by Mayer and Altmayer,[2] according to which the highest yield of ammonia was obtained from Saar coal containing 1·13 per cent. of nitrogen at 800° C. A large proportion of the ammonia which is evolved is decomposed when the temperature is raised further. It is only the slow rate of decomposition of ammonia gas and the protective action of the other gases and vapours which are simultaneously evolved which prevent its complete decomposition. Volkmann [3] states that very few gas works in Germany obtain more than 10 kg. of ammonium sulphate per ton of coal, and the yield is usually lower. On the other hand, coke ovens obtain as much as 15 kg. of sulphate per ton ; the average yield of all the coke ovens in the Ruhr district is 12·5 kg. per ton. The following yields are obtained per ton of coal :—

	Kg. of Ammonium Sulphate.
Westphalian gas coal, average of 6 gasification tests	10·4
Westphalian cannel coal, average of 3 gasification tests	7·7
Westphalian coking coal, average of 9 gasification tests	11·0
Upper Silesian gas and coking coal, average of 9 gasification tests	13·5
Lower Silesian gas coal, average of 2 gasification tests	7·7
Lower Silesian coking coal, average of 3 gasification tests	8·4
Saar gas and coking coal, average of 6 gasification tests	8·2
English gas coal, average of 3 gasification tests	13·4

According to the communications of H. Koppers, Essen, in the most up-to-date American coke ovens, the Seabord By-Product Company, of New Jersey, and the Carnegie Steel Company, at Clairton, obtain an average of 12·5 kg. of sulphate per ton of coal which is coked.

Two methods are recognised of obtaining ammonia from the gases from the distillation of coal—namely the so-called washing process, and the direct absorption process. Modern coke ovens seldom use the old washing process, which is in general use in gas works. This depends, as its name implies, on washing the ammonia out of the gases with water and then liberating it from the gas liquor by steam distillation in presence of lime. In gas works with effective cooling the gas water contains 30 to 50 gm. of NH_3 per litre, but where the cooling is less efficient, as in coke ovens, only 8 to 15 gm. of NH_3 per litre is obtained. The ammonia in these liquors is present both as volatile compounds—such as the carbonate and sulphide—and as fixed salts, more particularly the chloride. The direct method of ammonia recovery depends on the passage of

[1] Ullmann, "Encyclopædia," i. (1914), pp. 360 *et seq.*
[2] *Journ. f. Gasbel,* **50,** 49 (1907).
[3] "Chemische Technologie des Leuchtgases," Leipzig, 1915, pp. 49 *et seq.*

the crude gas containing ammonia through a bath of sulphuric acid, by which means ammonium sulphate is obtained directly, with considerable saving of steam. It was soon found that an absolutely direct process was not suitable if only for the reason that it was very difficult to separate the tar in a hot condition. The most important of the coking firms, such as Heinr. Koppers, of Essen, and Dr. C. Otto & Co., of Dahlhausen, have therefore studied these processes for more than fifty years, and have developed a semi-direct process which was introduced into many coke ovens about 1909. By this method the gas, which is actuated by fans, is cooled to 30° C. in order to separate the tar; in this way the tar, naphthalene, water are separated, and all the fixed ammonia and a certain amount of the free volatile ammonia are obtained in the form of an aqueous solution. The gases which pass the coolers are pre-heated to 60° C., and then passed into the saturators, where ammonium sulphate is formed; they are now practically free from ammonia and pass through an acid separator directly into the gas holders or to the place where they are used. The condensed aqueous liquors have to be distilled with the addition of slaked lime in the usual columns. The ammonia which is thus liberated is returned to the gas stream, and passes with this into the saturator. This semi-direct method has been developed more particularly by H. Koppers. It does not attempt to remove all the ammonia from the coke-oven gases in one operation, but, on the other hand, it avoids contamination of the ammonium sulphate by tar, and also prevents naphthalene, which is very volatile, from being carried into the gas main, where it may cause permanent stoppages; it also ensures the complete separation of the tar. Whereas this process was at one time used exclusively by the coke ovens, it is now also used by various gas works, being introduced at Buda-pest in 1913, and at Königsberg in 1916, as it has now been shown that the illuminating gas is in no way depreciated by the sulphuric acid. According to a communication of H. Koppers,[1] the American Seabord By-Products Company find that the ammonia liquor drawn from the coolers, contains an average of 7 gm. of NH_3 per litre, half of which is fixed and half volatile. When working continuously, the saturators contain 5 per cent. of free sulphuric acid. The gas in front of the saturators contains 8 gm. of NH_3 per cu. m., and behind them 16 gm. NH_3 per 100 cu. m. The saving of steam, which is the main item of cost, is very much greater by modern methods than by the washing process, but can be improved to a considerable further extent by pre-warming the ammoniacal

[1] *Mitteilungshefte*, 1919, No. 9, and 1920, Nos. 1 and 6.

liquor before distillation and by working the distilling columns with waste steam. H. Koppers gives the following data :—

Summary of Steam used for the Distillation of Ammonia Liquor per ton of Ammonium Sulphate produced

		Steam consumed in Tons.
(a) Coke Oven Plant :—		
Washing process . .	(1) Without pre-heating of the ammonia liquor . .	6·300
	(2) With pre-heating of the ammonia liquor . .	4·015
Koppers process . .	(1) Without pre-heating of the ammonia liquor . .	2·860
	(2) With pre-heating of the ammonia liquor . .	1·820
Koppers process, distilling column heated by waste steam.	(1) Without pre-heating of the ammonia liquor . .	0·225
(b) Gas Works :—		
Washing process . .	(1) Without pre-heating of the ammonia liquor . .	4·320
	(2) With pre-heating of the ammonia liquor . .	3·170
Koppers process . .	(1) Without pre-heating of the ammonia liquor . .	1·510
	(2) With pre-heating of the ammonia liquor . .	0·980
Koppers process, distilling column heated by waste steam.	Without pre-heating of the ammonia liquor . .	0·225

According to the German maximum price of March 1st, 1920, 100 kg. of ammonium sulphate cost about 250 marks. For a rough calculation one may assume that for the production of this amount of the sulphate 100 kg. of acid of 60° Bé., and 25 kg. of ammonia (NH_3) are necessary. Now, the position of the German sulphuric acid industry is very bad in consequence of lack of raw material. Sulphuric acid is so scarce that the coking industry is not able to maintain the output which is economically desirable. According to the schedule of maximum prices for March 5th, 1920, German domestic sulphuric acid of 60° Bé. cost 60 marks per 100 kg. According to the above summary by Koppers, for the production of 100 kg. of sulphate from coke-oven gas about 200 kg. of steam are required, which, at 30 marks per ton of steam, amounts to 8 marks. According to a pre-war calculation, which we have already given, the cost of conversion of ammonia into ammonium sulphate was about 1·9 pfg. per kilogram of sulphate, and may be assumed to be 29 marks per

100 kg. in 1920. According to these data, we find that the coke ovens can work at a profit at the present maximum price and with domestic sulphuric acid; it would not be possible for them to work at a profit with foreign sulphuric acid produced from pyrites, of which the average cost is 250 marks per 100 kg.

On the other hand, the price of ammonium sulphate was fixed at such a figure that under favourable circumstances—namely, very low transport charges for sulphuric acid, low overhead charges and cheap steam—plants producing cheap synthetic ammonia could still compete. We have already estimated the production cost per kilogram of Haber ammonia in 1913–14 to have been about 32·5 pfg. If for 1920 we multiply the price fifteen-fold—that is, if we estimate it at 4·88 marks per kilogram of ammonia—a profit could still be secured with such ammonia at the producing locality. The situation becomes less favourable if the Haber ammonia has to be transported in the form of concentrated ammoniacal liquor, and rendered more expensive by the marketing and transport charges. The margin between production costs and sale price would then become so small that such ammonium sulphate could only compete under exceptionally favourable circumstances. For the production of 100 kg. of ammonium sulphate there are required about 100 litres of concentrated ammonia liquor containing 25 gm. of NH_3 per 100 c.c., or 131·61 litres containing 19 gm. of NH_3 per 100 c.c.

In England the maximum price for ammonium sulphate per ton carriage paid from June to July, 1920, was about £23 10s., that is, 48 marks per 100 kg. at the pre-war value of the German mark, or 364·25 marks at the rate of exchange of June 30th, 1920 (£1 = 155 marks). On the New York Exchange, ammonium sulphate was sold at the end of June, 1920, at $5 per 100 lbs., *i.e.*, 100 kg. for 42 pre-war marks, or 380 marks at the present rate ($1 = 38 marks). The French price for 100 kg. of ammonium sulphate at Paris was 175 fr., that is, 141·75 pre-war marks, or 546·88 marks at the present rate (1 fr. = 3·125 marks). In Sweden 100 kg. of ammonium sulphate was sold at 95 kr., or 106·40 pre-war marks. At the present exchange (1 kr. = 8·51 marks), this is 808·45 marks. Compared with these prices, the German maximum official price for 1920 of 250 marks was very low.

The position of the ammonium sulphate industry in Germany was so bad during the War that fears were entertained for its future. As the above considerations show, the conditions have meanwhile improved on account of a revised fixation of maximum prices. The difficulty of irregular deliveries of sulphuric acid remains, however, and renders manufacture very difficult. In conjunction with a coke-

oven by-product plant, the absorption of ammonia by sulphuric acid has the advantage of simplicity. So long as this is so, all endeavours to replace ammonium sulphate by other fertilisers will fail. The objections raised to the use of ammonium sulphate are that the useless sulphuric acid ballast, which it contains, is too high and that, moreover, this sulphuric acid tends to render the soil acid, and therefore injurious to plant life, by combining with lime. The present conditions, however, appear to render it desirable that most coke ovens and gas works should retain well-established methods and plant for the time being. Although, therefore, present conditions favour the further use of ammonium sulphate, which has proved eminently suitable in spite of all objections, the development of all methods of utilising the sulphur contents of the distillation gases for the purpose of fixing the nitrogen is most desirable, in view of present economic conditions in Germany. The magnitude of the sulphur contents of the German coal output has already been realised, but unfortunately no definite success has yet been attained in the direction of its utilisation. In 1913 A. Sander calculated that the sulphur of the coal which is used in coke oven and gas works alone corresponds to 510,000 tons of sulphuric acid of 60° Bé., a quantity of very considerable economic importance, as the total German production of sulphuric acid in 1912 was 1,650,000 tons of 100 per cent. H_2SO_4. The Burkheiser process (German pats. 212,209, 215,907, 217,315, 223,713) consists in passing the crude gas, freed from tar, over bog iron ore at 400° C.; this results in the combustion of the hydrogen sulphide to SO_2 or SO_3. Bertelsmann [1] states that the process has been tried at the gas works in Hamburg and Berlin-Tegel, and also at the Flemelle Grande coke ovens, near Liége, but has never been permanently introduced anywhere. In the process of W. Feld,[2] solutions of the sulphate and thiocyanate are used for fixing $NH_3 + H_2S$ [3] (see also German pats. 202,349, 237,607, 271,105; English pat. 3,061/1909; Belgian pat. 184,598; U.S. pat. 1,011,043). The trials of the process which were made at the gas works in Hamburg and Königsberg were in general favourable; the intention to use the process on a large scale has, however, been abandoned. The coking plant of the Gutehoffnungshütte at Sterkrade in Westphalia has meanwhile installed the Feld process, but nothing has been heard of the results during the last few years. The firm of Poetter tried a process at the Viktor Colliery at Rauxel, according to which coke-oven gas is washed with milk of lime in order

[1] Ullmann, "Encyclopædia," i. (1914), p. 413.
[2] *Zeitsch. f. angew Chem.*, 1912, p. 705.
[3] See also *Chem. Ztg.*, 1917, p. 657; Lunge-Köhler, "Steinkohlenteer und Ammoniak," Brunswick, 1912, pp. 165–170; *Chem. Ztg.*, 1914, p. 747.

to remove hydrogen sulphide. Similar attempts have been made by the Lothringen Colliery, one, for instance, in which the calcium sulphide liquor, which is obtained on distilling the ammoniacal liquor from the coke ovens with milk of lime, is decomposed by carbon dioxide, and the hydrogen sulphide which is liberated is burnt in a Claus furnace. The Leuna Works of the B.A.S.F. obtain finely divided sulphur by means of a contact process when freeing the producer gas for the Haber synthesis from H_2S.

During the War coke-oven by-product ammonia was the first, and for a long time the most important, raw material for the production of nitric acid by combustion. The plant at the Lothringen Colliery, near Gerthe, was more particularly arranged for the treatment of such ammoniacal liquor. At the end of 1917 forty tank waggons of concentrated ammoniacal liquor containing 16 to 18 per cent. NH_3, *i.e.*, about 600 cu. m. of liquor, could be dealt with daily. The collieries were officially ordered to concentrate the dilute ammoniacal liquor obtained from the washers. Even those plants which worked the direct process were ordered by the German Ministry of Munitions to hand over at least a portion of their production in the form of concentrated ammoniacal liquor. These circumstances, combined with the critical situation of the German sulphuric acid supplies, caused a serious decrease in the German supply of ammonium sulphate. On the other hand, the production of dilute and concentrated ammoniacal liquor produced in the plants of the firms already mentioned, Berlin-Anhaltischen Maschinenbau A.G., Jul. Pintsch A.G. of Berlin, Carl Still of Recklinghausen, and others increased.

The question which is so often put as to the relative costs of production of by-product and synthetic ammonia cannot be directly answered. In the production of synthetic ammonia, the costs of raw materials, wages, amortisation, etc., are fixed, whereas in coke oven or gas works the ammonia is actually a by-product, so that such calculations are impossible. For this reason, in the comparative table of production costs which we have already given, the production cost of synthetic ammonium sulphate only is given. It is, of course, quite possible to give costs for the wages, sulphuric acid, etc., involved in the conversion into sulphate, but no basis is possible for the cost of the ammonia itself This has, therefore, been taken as *nil*. It is clear that such estimates of production-cost do not give a clear picture of the situation.

The work which has been carried out in connection with the application of the gypsum process of the B.A.S.F. to concentrated ammoniacal liquor is of equal importance to the experiments of

Feld, Burkheiser and others. Obviously it would hardly be possible to apply the new process to each individual coke oven or gas works. Some sort of central organisation would be desirable for that purpose.[1] The attempts by H. Precht and others to utilise magnesium sulphate solutions, waste caustic potash liquors, and similar compounds, for the fixation of coke-oven ammonia, have not so far led to any industrial process (see German pats. 292,174, 292,209, 292,218, 294,857, 295,509),[2] although they are certainly promising. During the War sulphuric acid was replaced on a very large scale by sodium bisulphate, which was then available in large quantities as a by-product of the explosive industry. The corrosion of the lead lining of the saturators by accompanying nitrous gases was avoided by pre-heating the bisulphate solutions and diluting them with sulphuric acid. According to the composition of the bath, either almost pure ammonium sulphate or the double salt $Na(NH_4)SO_4$ is obtained.

The Deutsche Ammoniakverkaufsvereigung G.m.b.H., of Bochum, with a capital in 1915 of 456,300 marks, includes eighty members, among whom are such combinations as the Wirtschaftliche Vereinigung Deutscher Gaswerke A.G. in Cologne. The production of certain important collieries was already known, and the result of the negotiations between these producers and the B.A.S.F. has already been described. Before the War the sale of ammonium sulphate from Westphalia, which was graded as good grey quality, dry quality, ground quality, etc., was undertaken by the combination just mentioned, whilst sales from East Germany and Austro-Hungary were conducted by the Oberschlesischen Kokswerke und Chem. Fabriken A.G., in Berlin, which was in friendly relations with the Bochum Combination. The total deliveries of ammonium sulphate in 1913 and 1914 were as follows:—

	1913. Tons.	1914. Tons.
(1) By the constituent firms of the Ammoniak-V.-V.	324,280	406,476
(2) By the Upper Silesian coke ovens	2,508	1,797
(3) By the B.A.S.F., Oppau	—	1,450
(4) By the Comptoir Belge du Sulfate d'Ammoniaque, Brussels	8,145	4,144
(5) By Evence Coppée, Brussels	299	—
Totals	335,232	413,837

The sales of ammoniacal liquor were 2,620 tons in 1913 and 893 tons in 1914. Shortly after the outbreak of war the demand

[1] *Zeitsch f. angew. Chem.*, 1919, ii., 807.
[2] *Chem. Ztg.*, 1917, p. 421.

for ammonium sulphate was so lively that the supply was inadequate. Maximum prices were fixed in order to prevent profiteering by intermediaries. On account of the prohibition of exports at the end of September, 1917, foreign delivery contracts, such as those with America, had to be cancelled. In 1915 the demand was very large, and 364,077 tons of sulphate (25 per cent. NH_3) were sold, as against 406,476 tons in 1914. Very little of the salt was supplied to agriculture, as most had to be delivered to the works, where it was treated with milk of lime in order to produce ammonia for nitric acid manufacture. The possibility of supplying the market for agricultural fertilisers improved as the production of synthetic ammonia became effective. Meanwhile, the production of concentrated ammoniacal liquor became of increasing importance. The price was at that time quite unsatisfactory. The production gradually increased. In 1918 about half the production was disposed of as concentrated ammoniacal liquor and the other half as ammonium sulphate. The production was maintained at a constant level until November, 1918. In October, 1918, it was 31,000 to 32,000 tons (calculated as 25 per cent. quality), but has seriously declined since that time. The average production in 1918 was about 18,000 tons per month, and in April, 1919, it was only 7,000 tons The increase in the cost of labour and of raw materials, and the increasing difficulties of transport. and in obtaining the necessary acid, made the position so difficult that not only was the erection of new plant quite impossible, but even the improvement and maintenance of existing plant was extremely difficult. The commercial prices per 100 kg. of loose salt of 25 per cent. quality were 37·06 marks from January 1st to March 15th, 1919; 53·53 marks from March 16th to June 30th; 80·30 marks from July 1st to September 30th, and 111·18 marks from October 1st to December 31st. In 1920–21 the price was about 530 marks. The lack of coal was extremely serious. The sale of the product, which had so far been effected by the individual works, stopped in August, 1919, and was transferred to the Stickstoff-Syndikat G.m.b.H. in Berlin, which had meanwhile been founded. All deliveries from works which did not belong to the Syndicate were effected by the Deutsche Ammoniak-Verkaufsvereinigung in Bochum, from works lying west of the Elbe, excepting gas works, which supplied through the Wirtschaftliche Vereinigung Deutscher Gaswerke (Berlin branch). After long negotiations, a coke-oven by-product trust was formed in Upper Silesia at the commencement of 1920, which controlled an output capacity of 20,000 to 30,000 tons of ammonium sulphate. The share of Upper Silesia in the by-product manufacture of Germany is very considerable. In

1913 15 per cent. of the production of tar, 9 per cent. of the production of ammonium sulphate, and 18 per cent. of the production of benzole came from the Upper Silesian works.

Fortunately coking without the recovery of by-products has decreased greatly in Germany. According to Ost ("Lehrbuch d. Chem. Technologie," 10th edition, Leipzig, 1919, p. 356), in the Ruhr district (Oberbergamtsbezirk Dortmund) there were, in 1900, 99 works, comprising 9,948 ovens, of which only about 30 per cent. were distillation ovens with by-product recovery—namely, 1,182 according to the system of Hoffmann-Otto, 1,046 bottom-fired ovens, 346 Brunck ovens, and 390 of other makes: total, 2,964. In 1912 there were in the German Empire 178 coke works containing 20,738 working ovens, of which only 3,281—that is, 16 per cent.—did not recover by-products, as compared with 22 per cent. in 1909. The total production at that time was 31·3 million tons of coke, of the value of 506,000,000 marks (at 16·2 marks per ton), and 407,000 tons of ammonium sulphate, of the value of 99·3 million marks (at 244 marks per ton).[1]

The 1,700 German gas works produced in 1913 2,700 cu. m. of lighting gas; 4·8 million tons of coke, valued at 88,000,000 marks; 76,000 tons of ammonium sulphate, valued at 16·2 million marks; 1,800 tons of cyanogen compounds, of the value of 1·3 million marks, and so forth. The annual German production of 549,000 tons of ammonium sulphate in 1913 was far greater than that of any other country. The world's production in 1913 was 1·41 million tons. The rapid increase in the German production of ammonium sulphate is shown by the following figures for the annual production in tons:—

	Tons.		Tons.
1896	75,000	1907	287,000
1900	120,000	1908	313,000
1902	135,000	1909	323,000
1903	140,000	1910	373,000
1904	182,000	1911	418,000
1905	203,000	1912	492,000
1906	235,000	1913	549,000

The average proportion of the coke-oven industry in this output is 85 per cent. The production figures of the Ammoniak-V.-V., which

[1] German coal production:
1919 . . 116·68 million tons.
1920 . . 131·34 million tons (without the Saar and the Palatinate).
German coke production:
1919 . . 22·015 million tons.
1920 . . 25·177 million tons (without the Saar and the Palatinate).
German production of coal briquettes:
1919 . . 4 million tons.
1920 . . 4·96 million tons (without the Saar and the Palatinate).
Compare *Metallbörse*, 1921, p. 306.

have already been given, show that the German production of by-product ammonia during the War was maintained at an essentially satisfactory figure ; during the latter part of this period, half of it was in the form of concentrated ammoniacal liquor. On the other hand the production of ammonium sulphate from the nitrogen of coal in 1919 was only about 250,000 tons (calculated as 25 per cent. NH_3), and has thus declined considerably.

In 1914 the German production of ammonium sulphate considerably exceeded the domestic consumption, for German agriculture consumed :—

	Tons.
1909	275,000
1910	350,000
1911	370,000

From 1906 onwards, exports were larger than imports, which declined continuously. Great Britain exported 30,545 tons to Germany in 1909, but only 2,740 tons in 1911. The figures for the German exports in 1912 and 1913 were :—

	1912. Tons.	1913. Tons.
To Belgium	19,723	15,774
,, Denmark	72	455
,, France	4,313	7,428
,, Italy	3,816	3,550
,, Holland	19,121	18,195
,, Switzerland	1,447	1,337
,, Spain	855	2,550
,, Ceylon	43	818
,, Hawaii	—	2,541
,, Java	5,620	16,023
,, U.S.A.	902	5,629
,, Brazil	965	428
Total	56,877	74,738

So long as England controlled the ammonium sulphate industry English prices were the basis of the trade. In 1911, for example, the price was 27·56 marks per 100 kg. In the years immediately preceding the War, however, Germany had its own prices. These prices per 100 kg. were :—[1]

	Marks.
1906	23·83
1907	23·65
1908	23·92
1909	23·29
1910	23·32

[1] See Bertelsmann, Ullmann's "Encyclopædia," i. (1914), p. 413.

	Marks.	
1911	26·85	
1912	28·35	
1913	28·06	
May 27th, 1915	24·30	Maximum prices, loose.
June 1st, 1918	37·06	
December 31st, 1919	about 115·00	
March 1st, 1920	about 250·00	
June 1st, 1921	about 300·00	
October 10th, 1921	about 360·00	
December 5th, 1921	about 530·00	
February 8th, 1921	about 620·00	

The price of 1 kg. of ammonia in the form of concentrated ammoniacal liquor was 79 pfg. in 1910, 80·65 pfg. in 1911, 96·25 pfg. in 1912, and 92·13 pfg. in 1913. The manufacture of dilute and concentrated ammoniacal liquor only attained large dimensions during the War. According to N. Caro,[1] it amounted to 580 tons in 1900, 1,180 tons in 1902, 1,680 tons in 1904, and 2,500 tons in 1906; 2,620 tons were disposed of in 1913, and 893 tons in 1914. According to the figures of the Ammoniak-V.-V., however, about 200,000 tons of NH_3 were produced in the form of concentrated liquor in their works alone in 1918.

It is impossible to describe here all the processes in which ammonia is obtained as a by product, such as the distillation of bones, molasses, residues, and so forth. The utilisation of inferior coal, such as wash dumps, etc., by the Mond gas process was first carried out in England. The German Mond Gas Company erected the first German plant at the Mont-Cenis Colliery, near Sodingen in Westphalia. According to Caro, this plant produces from 1 ton of coal 40 kg. of ammonium sulphate (70 to 80 per cent. yield of nitrogen), and 3,500 cu. m. of gas of 1,100 to 1,200 C.H.U.[2] The extension of this process to peat is very promising. A. Frank [3] gives the following figures for the extent of the German peat moors :—

	English Square Miles.
Province Hanover	2,180
Province Pomerania	1,200
Province East Prussia	763
Province Rhineland	371
Bavaria	327
Oldenburg	1,525
Württemberg	174
The rest of Germany	2,180

[1] "Die Stickstoffrage in Deutschland," Berlin, 1908.
[2] See Ferd. Fischer, "Kraftgas, seine Herstellung und Beurteilung," Leipzig, 1911; F. Muhlert, "Die Industrie der Ammoniak-und Cyanverbindungen," Leipzig, 1915.
[3] *Chem. Ztg.*, 1908, p. 580.

These 400 German square miles, or 2,250,000 hectares of moorland, contain, on an average, 4,000 tons of peat per hectare, assuming a thickness of 3 m.—that is, a total of 9,000,000,000 tons of dry peat. The Oberbayrischen Kokswerke und Fabriken Chemischer Produkte A.G. in Beuerberg (Isartal Railway) use the Ziegler process of treating compressed peat. The Wieland process, which is similar, produces peat coke ; from 100 kg. of peat, containing 25 per cent. of water, 33 kg. of good peat coke, 4 kg. of tar, 0·6 kg. of ammonium sulphate, 0·5 kg. of calcium acetate, and 0·3 kg. of wood spirit are obtained. The experiments of N. Caro, and A. Frank, and Ludwig Mond,[1] are of still greater interest (see German pat. 238,829). These were carried out with ordinary peat containing 50 to 60 per cent. of water. Although the results obtained at Stockton and Winnington showed the practicability of the method, the figures obtained at the experimental plant at the Mont-Cenis Colliery at Sodingen in Westphalia were still more favourable. At this plant, 45 tons of peat, containing 42 to 47 per cent. water, from the Nord-georgfehn-Marcard-Moor Canal, were gasified in 24 hours ; per ton of dried peat, 2,800 cu. m. of gas were obtained of calorific value 1,400 cals. per cu. m., and of the following composition :—

17·4 to 18·8 per cent. CO_2
9·4 to 11·0 per cent. CO
22·4 to 25·6 per cent. H_2
2·4 to 3·6 per cent. CH_4
42·6 to 46·6 per cent. N_2
Traces of oxygen ; no tar fog.

The power obtained in a gas engine was found to be 1,000 b.h.p. hours per ton of dry peat. The material used contained, when dry, 1·05 per cent. N and 3 per cent. of ash. In these experiments 40 kg. of ammonium sulphate were obtained per ton of dry peat (representing a nitrogen yield of 77 to 80 per cent.) compared with 10 to 12 kg. per ton of coal. In Stockton, with peat containing 2·8 per cent. N (when dry), 110 kg. of ammonium sulphate were obtained, representing an 83 per cent. yield. If a power station of 1,000 h.p. were driven with power gas from peat, then at pre-war prices and assuming a liberal wages bill, 15 per cent. interest and amortisation, the cost price per horse-power year would amount to 40 to 50 marks, which is as low as is possible with water power. Such a 1,000-h.p. power plant would utilise 16,000 tons of raw peat, or 8,000 tons of dry peat per annum, and would therefore reclaim 2 hectares of moorland if this were 3 m. thick. The power and nitrogen obtainable

[1] *Chem. Ztg.*, 1908, p. 580 ; 1910, p. 1015 1911, pp. 505, 515.

from the German moors is thus extraordinarily large, as with certain qualities which contain a higher nitrogen content of 1·5 to 2 per cent. the conditions are still more favourable. In spite of the very promising results of these experiments, the gasification of peat, which is of prime importance to the nitrogen industry, as a source both of ammonia and of power, has nowhere been introduced on a continuous large scale, as its economic value has not yet been definitely established. At the suggestion of N. Caro and A. Frank, the Mond Gas Company built a 4,000-h.p. plant in 1910 at the Schweger Moor, near Osnabrück. This plant was closed during the War, but has been reopened; at present, however, it does not produce ammonium sulphate. The largest peat power stations—for example, the one at Wiesmoor, near Aurich—usually burn air-dried peat directly under steam boilers, for which purpose 50 hectares of moorland have to be used per 10,000-h.p. years. Gebr. Körting gasify peat by the Ost process in gas producers, and use it to drive suction gas motors. It may be mentioned here that at Carnlough, in Ireland, a plant was worked by the Woltereck process,[1] and produced in 1909 about 5,000 tons of ammonium sulphate, being 5 tons of sulphate per 100 tons of dry peat. The Ekenberg process was worked by Wet Carbonizing, Ltd., of London, which was founded in 1912, but the works had to be closed down on account of the steadily increasing deficit. It is impossible to consider here the gasification of *Seeschlick* or *Mudde* (a muddy deposit found in estuaries), which was investigated by Deutsche Ammoniakwerke, Ludwigshof.

The distillation of oil shale, which yielded 57,000 tons of ammonium sulphate in Scotland in 1909, has latterly become of increasing importance in Germany. Before the War oil shale was worked by the Messel Pit, near Darmstadt, on a very small scale only; this shale contains 40 to 45 per cent. of water, and yielded 6 to 10 per cent. of tar (crude oil), and 40 to 45 per cent. of residue. From 1,000 kg. of this shale they obtain 135 litres of crude oil, 295 litres of ammoniacal liquor, and 59 cu. m. of gas. The shale deposits of Württemberg are very considerable, but their exploitation was only recommenced during the war period, when raw materials were scarce. The deposits are believed to contain 10,000,000,000 tons of shale. Bituminous shale has also been found in the south of the Province Hanover and in the Franconian Jura[2] (Jura-Ölschieferwerk, Stuttgart).

A considerable source of ammonia is presented by urine, the urea of which soon changes to ammonium carbonate. According to

[1] *Chem. Ztg.*, 1909, p. 277.
[2] *Umschau*, 1920, p. 408.

Ost, 100,000 persons annually produce 600 tons of NH_3, but, according to F. Fischer,[1] they only produce 432·1 tons of NH_3 in the urine and 59·4 tons in the fæces—that is, together, 482·5 tons of NH_3. The treatment of dilute sewage effluents is uneconomic, and they are usually utilised on sewage farms. 13,000 tons of ammonium sulphate were, however, produced from sewage in France in 1905, of which 10,000 tons were from Paris. The French production was 12,000 tons in 1913, but only 5,500 tons in 1917. In Kiel they have an earth closet system, in conjunction with which they produce briquettes from the fæces. In 1913 they obtained from 14,170 cu. m. of fæces 1,640 tons of briquettes containing 6·2 per cent. N, 2·6 per cent. P_2O_5, and 2·7 per cent. K_2O. In Cologne, a company named Pudrette-Dünger G.m.b.H. was formed in 1917 for similar purposes. The utilisation of farmyard manure is more important than that of human beings. The urea in the former very rapidly changes to volatile ammonium carbonate, and, in consequence of unsuitable methods of storage as much as 50 per cent. of the valuable nitrogen contents are usually lost. The work of Gerlach and others has convincingly shown the value of suitable methods of preservation by the addition of potash salts, bisulphate, superphosphate, gypsum, formalin, peat litter, etc.

The question of the production of nitrogen compounds as a by-product of the distillation of coal is closely connected with coal production, with low temperature carbonisation, and with centralisation of our power resources. These problems cannot be closely considered within the limits of this book, which is only concerned with the description of actual synthetic processes. The German figures for coal and lignite production are as follows (in million tons, the lignite figures being given in brackets) :—

1913 . .	192	(87)	1917 . . .	167	(95)
1914 . .	162	(84)	1918 . . .	160·50	(100·6)
1915 . .	147	(88)	1919 . . .	116·50	(93·8)
1916 . .	159	(94)	1920		(111·6)

The figures for lignite production are of special interest to the nitrogen industry, as they illustrate to some extent the industrialisation of the Central German lignite fields. W. Gluud and P. K. Breuer[2] have investigated the fate of the nitrogen during low temperature carbonisation. The Institute for the Investigation of Coal (Institut für Kohlenforschung) at Mülheim (Ruhr), has made a special study of the properties of ordinary coal, and in the same manner the Institution for the Investigation of Lignite (Braunkohlenforschungs-

[1] "Das Wasser," Leipzig, 1914.
[2] *Chem. Zentralbl.*, 1919, iv., 1066.

institut), at Freiberg-i.-Sa., has studied lignite ; in this connection it has investigated methods of rendering the nitrogen in lignite available. The literature on the connection between problems of heating, fuel and nitrogen is extraordinarily extensive, in accordance with its exceptional economic importance. Not only is the utilisation of the enormous nitrogen contents of the German coal output of great importance, but the serious circumstances of the times have drawn attention to the fact that the German coal reserves are not inexhaustible, and have made coal and heat economy and the centralisation of power supply imperative. Moreover, these problems are closely interconnected with the question of State revenue. According to calculations, 192,000,000 tons of coal, with 0·2 per cent. yield of nitrogen, should provide on distillation 384,000 tons of nitrogen, corresponding to about 1·92 million tons of ammonium sulphate per annum. This calculation is very easy to make, but very difficult to translate into practice ; if, however, this could be done, it would completely change our economic and industrial life. It is found, however, that the problems of the supply of sulphuric acid, of the erection of the necessary plant, the centralisation of the production of power gas, the modification of numerous individual coal-power installations, and, finally, the utilisation of enormous quantities of coke—or, as an alternative, the so-called complete gasification of the coal—are so complicated that a solution can only be attempted step by step, and this is being actually done. The criticism that if the completion of by-product plants had been more quickly effected the synthetic production of nitrogenous manures would have been rendered unnecessary is entirely unjustified, particularly as it lacks the wide view which is necessary in considering this problem. A series of valuable contributions to the solution of these problems have been made by P. W. Uhlmann, Ed. Donath, E. K. Besemfelder, A. Naumann, N. Caro, Fr. Schäfer, Gwosdz, H. R. Trenkler, W. A. Dyes, H. Strache, Brabbée, G. Klingenberg, F. Russig, and Lempelius.[1]

Ammonia is not the only product of the lighting-gas industry of interest here, as spent oxide from the purifiers is a raw material for the manufacture of sulphuric acid and the production of cyanogen compounds. The official maximum price for sulphur in this material was 66

[1] *Chem. Ztg.*, 1915 pp. 713, 918, 925 ; 1916, pp. 285 469, 701 ; 1917, pp. 93, 393, 605, 625, 721, 737, 785, 799, 806, 583 ; 1918, pp. 281, 320, 404, 489 ; 1919, pp 11 281, 455, 521, 604, 865 ; *Chem. Techn. Übers*, 234 ; 1920, pp. 57, 197 ; Österr, *Chem. Ztg.*, 1918, p. 151 ; *Zeitsch. d. Ver. Deutsch. Ing.*, 1919, p. 133 ; *Zeitsch. f. angew, Chem.*, 1919, I., 210 : 1920, I , 9 ; "Technik u. d. Landwirtschaft," 1919, p. 233 : *Chem. Zentralbl.*, 1919, II., 25, 26 ; iv., 547, 632 ; *Umschau*, 1920. pp. 42, 81, 126 ; "Die Rationelle Ausnutzung der Kohle. Techn. Gutachten zur Vergasung und Nebenproduktongewinnung. Herausgegeben vom Reichsschatzamt," Berlin, 1918.

to 120 pfg. per kilogram in the spring of 1922. According to the Wirtschaftliche Vereinigung Deutscher Gaswerke A.G. of Cologne, to which 607 works belonged on March 31st, 1918, the quantity of spent oxide from gas purifiers which is annually sold in Germany amounts to 82,000-90,000 tons—*i.e.*, 30,000 tons of sulphur assuming an approximate content of 35 per cent. The proposal has been made to use this spent oxide and gas liquor directly as an agricultural fertiliser and for the destruction of weeds and insect pests.[1] The crystallised potassium ferrocyanide obtained from spent oxide corresponds to 10 to 12 per cent. of cyanogen in the form of Prussian blue; there is also present 1 to 4 per cent. of ammonium sulphocyanide; 1 to 4 per cent. of ammonium sulphate, and, as already mentioned, an average of 30 to 40 per cent. of sulphur. The production of cyanogen compounds from spent oxide is a relatively easy process. Spent oxide therefore presents a partial solution of the problem of simultaneous fixation of the sulphur and nitrogen in coal. Methods of "wet washing" have latterly been introduced, and have proved successful, more particularly Bueb's process (German Patent 112,459). Bueb washes the gas with a solution of ferrous sulphate. We cannot consider this process in detail here, but must refer to the publications of Volkmann and Muhlert, already referred to, as well as to the Fortschrittsberichte of Waeser in *Chem. Ztg.*, 1913, No. 110; 1915, No. 118, 119, p. 741; 1919, No. 131, p. 890. The chapters on cyanogen compounds and on lighting gas in Ullmann's "Encyclopædia"[2] by W. Bertelsmann are very valuable. The production of cyanide during the gasification of molasses residues (German pat. 86,913 and others) by the method of Reichardt and Bueb is important. It was first operated commercially by the Zuckerraffinerie Dessau in 1898. The Deutsche Gold- und Silberscheideanstalt A.G. of Frankfurt-a.-M. works the process of Castner, which utilises sodium and ammonia (German pat. 90,999), etc. There is a similar but older method of Stassfurter Chem. Fabrik Vorm. Vorster & Grüneberg A.G. of Stassfurt, which depends on German pat. 38,012 of Siepermann, who treats mixtures of alkali and carbon with ammonia at a dull red heat. A similar process by Beilby (German Patent 74,554) has been practised by the Cassel Gold Extraction Company in Glasgow since 1892.

We are here interested in attempts to utilise the nitrogen of the air directly for the production of cyanides. The pioneers in this direction were Possoz and Boissière, who treated wood charcoal

[1] *Chem. Ztg.*, 1920, p. 171; *Journal f. Gasbel*, 1918, p. 121.
[2] Vol. iii. (1916), pp. 594–628, and vol. vii. (1919), pp. 567–610.

soaked in a solution of alkali in vertical retorts with flue gases at a white heat in 1843. Attempts have also been made to synthesise hydrocyanic acid directly from its elements with the help of the energy of the electric arc. Dewar carried out experiments in 1879,[1] and they have been continued by O. Dieffenbach, W. Moldenhauer and Chem. Fabr. Griesheim-Elektron (German Patents 228,539 and 255,073), and by Konsortium für elektrochemische Industrie G.m.b.H. of Nürnberg (now of Munich) (German Patents 263,692 and 268,277); also by A. Helfenstein (German Patent 262,325). The process of J. E. Bucher, which has been taken up by the Nitrogen Products Company of Providence, U.S.A., promises to become important. It depends on passing a current of nitrogen at 900° C. over a mixture of equal parts of sodium carbonate, graphite, or coke and iron powder. This interesting method is closely associated with the nitrogen industry, and will be discussed in more detail later (see, for example, German Patent 286,086). A process has been developed by A. R. Lindblad (German Patent 293,904), who obtains cyanide in an electric furnace from potash, charcoal and nitrogen, and has been developed at the Sandsta Elektriska Smältverk. It is intended that the process shall be worked by the Aktiebolaget Cyanid at Trollhättan.

As is shown by the historical development of the calcium cyanamide industry, which has already been described, the cyanide industry is the real origin of the nitrogen fixation industry.

The lime industry, which is closely connected with the nitrogen fixation industry, is controlled by the Deutsche Kalkbund, which was founded in 1919. The distribution of this commodity in April, May and June, 1920, in tons, was as follows (the figures for the third quarter of the year were very similar) :—

Consuming Groups	April		May.		June.	
	Alleged Demand	Supply.	Alleged Demand.	Supply	Alleged Demand.	Supply.
Iron and steel industry .		47,000	115,740	50,000	116,780	50,000
Calcium cyanamide industry .		28,000	35,500	32,500	40,500	35,000
Chemical industry .		24,000	68,760	24,000	69,540	24,000
Coke ovens and gas works .		4,000	4,000	4,000	4,000	4,000
Lime as fertiliser . .	768,450	70,000	263,300	25,000	244,400	15,000
Lime for building trade .		46,000	262,820	77,000	329,700	83,000
Lime - sandstone industry (artificial stone industry) .		10,000	19,550	12,500	20,950	14,000
		6,000	13,000	10,000	14,000	10,000
Totals . . .	768,450	235,000	782,670	235,000	839,870	235,000

[1] *Chem. News*, **39**, 282.

According to an order of the Imperial Government, the requirements of the nitro-lime industry have priority. An increased production of lime, more particularly for building and fertilising purposes, is not to be hoped for until larger coal supplies are available. According to the data of the Verein Deutscher Kalkwerke, the supply of lime to agriculture in former years was as follows :—

	Burnt Lime. Tons.	Unburnt Lime. Tons.
1913	2,121,174	1,398,184
1914	1,042,127	947,325
1915	821,313	857,975
1916	837,419	896,529
1917	816,921	789,968

This rapid decrease in the supply of lime explains the preference of agriculturalists working land deficient in lime for calcium cyanamide which contains much lime, and thus supplies two important fertilising elements to the land. On the other hand, it must be mentioned here that many agriculturalists object to calcium cyanamide, in consequence of its dust-producing and corrosive qualities. It will, therefore, remain as an aim of this industry to remove these objectionable qualities from this otherwise excellent fertiliser. We will show later that the addition of oil has so far proved the best remedy for these disadvantages, but unfortunately it has been impossible to employ this method in Germany latterly in consequence of the shortage of suitable oil.

In general there was an increasing disinclination amongst agriculturalists in 1920 to utilise nitrogenous fertilisers, as the price of these had risen so greatly. This unfortunate result is due to the fact that it has been found impossible to produce an increased harvest corresponding in value to the manure which is employed, particularly on lighter soil, and this is in turn closely connected with the greatly increased cost of agricultural wages, materials and implements, and, last but not least, with the demand for the removal or modification of the State control of agriculture. The cases of the small, middle, and large landholder differ, of course, considerably, as their economic conditions are on a quite different footing. The circumstances which have been described have led to the cancellation of individual orders for fertilisers. The industry would be wise to heed these warnings. The economic success of the nitrogen industry at present depends on the cost of fuel, wages, and so on, just as the return of agriculture does on the prices fixed for its products. Under normal conditions prices would have been settled by the circumstances of supply and demand ; it is questionable whether this is the case

to-day, and further interference by the State may be necessary during the intermediate period. The State is interested in these matters from many points of view. It has not only to consider the interest of the capital which it has invested in the atmospheric nitrogen industry, but it must also endeavour to cheapen and improve the food supply, which is identical with the productivity of agriculture, this being one of the main factors in the recovery of German economic conditions. The general educated public supposes that an increase in the potash industry would suffice for this purpose, this supplying a German natural product, which would perhaps be cheaper than synthetic nitrogenous fertilisers. But the soil only yields a high return if it is supplied with all the mineral fertilisers—potash, phosphoric acid, nitrogen, lime, and so forth—in sufficient quantity. According to the remarkable law of the minimum, discovered by Liebig, the quantity of the crop is controlled by that of the fertilising ingredient which is relatively deficient, so that ample fertilisation with potash salt and basic slag is comparatively useless if there is a deficiency of nitrogen in the soil. This simple consideration alone explains the vital importance of the nitrogen industry, which has changed in character since the war period, but is none the less important to the community. During 1921 the market position of the German nitrogen industry decidedly improved.

The German Government interests in the nitrogen industry and in the closely connected large-scale production of electric power are now dealt with by the Industrial Division (First Division) of the Imperial Exchequer.

The development of the nitrogen industry had a stimulating effect on the manufacture of industrial gases. Pure nitrogen is required for the production of nitro-lime, and nitrogen and hydrogen for the Haber synthesis of ammonia. Initially the nitro-lime industry produced nitrogen by passing air over red-hot copper turnings, which were periodically regenerated by reducing gases after they have been converted into oxide. This rather primitive method was soon abandoned. The nitrogen for the manufacture of nitro-lime is now obtained almost entirely by the distillation of liquid air. Plant for this purpose is built in Germany by the Gesellschaft für Lindes Eismaschinen A.G. (Abteilung Gasverflüssigung) of Höllriegelskreuth, near Munich, and also by the Gesellschaft für Apparatebau P. Heylandt m.b.H. of Berlin-Mariendorf. The enormous development of the technology of liquefied gases is shown by the following figures of the Linde Company of plant already erected or in course of erection :—

	Liquid Air Plants	Oxygen Plants		Nitrogen Plants.		Hydrogen Plants.	
		Number	Annual Output.	Number	Annual Output.	Number.	Annual Output.
			Cubic Metres		Cubic Metres		Cubic Metres.
November, 1916	95	160	47 million	50	238 million	17	27 million
October, 1918 .	120	209	72·5 million	55	310 million	18	29 million

In 1912 there were only 81 oxygen plants, 22 nitrogen plants, and 12 hydrogen plants. Whilst the fractionation of liquid air is comparatively simple, on account of the differences of the boiling points of oxygen and nitrogen (− 182° C. and − 195° C.), the production of hydrogen by the Linde-Frank-Caro process from water gas is more complicated. The average composition of water gas is :—

48 to 52 per cent. H_2,
42 to 44 per cent. CO,
5 to 2 per cent. CO_2,
5 to 3 per cent. N_2,

with varying amounts of oxygen, methane and sulphur and phosphorus compounds. From this mixture carbon dioxide is removed by absorption and nitrogen, carbon monoxide and the other impurities by cooling with liquid air. Hydrogen boils at − 253° C., and therefore remains gaseous. A gas is first obtained containing 97·0 to 97·5 per cent. by volume of hydrogen, which can be freed from the remaining traces of carbon monoxide by treatment with soda-lime under pressure, and then contains 99·2 to 99·4 per cent. of hydrogen, together with 0·8 to 0·6 per cent. of nitrogen.

The price of gases obtained by liquefaction is naturally dependent on the cost of the raw material and the scale of manufacture. With a plant of average size, under normal conditions in the pre-war period, impure hydrogen could be manufactured at a price of about 12 pfg. per cu. m., and the purified gas at 14 pfg. per cu. m. The data of the Lindegesellschaft on the manufacturing costs of nitrogen under pre-war conditions are exceedingly interesting (see table on p. 88).

The large Linde plants of the nitrogen industry probably supplied nitrogen during the first years of the War at 1 to 1·5 pfg. per cubic metre. Such nitrogen was easily obtained of 99·5 per cent. purity. The industry is so large that the quantity of oxygen obtained as a by-product is also very large, and in future this gas must be considered as a cheap by-product. C. von Linde has already called attention to

Capacity: Cubic Metres per Hour	40	400	4,000
	Marks.	Marks.	Marks.
Power: 1 h.p. = 10 pfg.	3·60	—	—
1 ,, = 6 ,,	—	9·60	—
1 ,, = 1 ,,	—	—	9·50
Wages: 1 mechanic and 1 assistant	2·00	2·00	—
1 ,, ,, 3 assistants	- -	—	3·80
Lubricating oil	0·30	0·50	1·80
Caustic soda	0·10	0·30	2·50
Calcium chloride, water, cleaning material, etc.	0·10	0·40	1·50
Working costs per hour	6·10	12·80	19·10
Works costs per cubic metre of nitrogen in pfennigs	15·20	3·20	0·48

the technical uses of such oxygen [1] and reported in the same publication on the first attempts to use "Oxyliquit" explosives during the construction of the Simplon Tunnel. The use of liquid air or liquid oxygen explosives for the blasting of rock, for removing tree stumps, and so on, is already extensive. We may mention in this connection the processes of the Sprengluft-Gesellschaft, of Berlin.

The process of the B.A.S.F., the technical details of which will be discussed later, is of much interest. The B.A.S.F. produces a portion of the necessary nitrogen in a Linde plant and the rest from producer gas. Producer gas, water gas, and steam are caused to interact in presence of a contact mass containing metallic oxides of the iron group. The carbon monoxide of the water gas and the producer gas reacts according to the following equation:—

$$CO + H_2O = CO_2 + H_2.$$

The carbon dioxide which is formed is removed by absorption in water under pressure. The last traces of carbon monoxide are absorbed by ammoniacal cuprous oxide solution or a similar reagent, and the remaining gas then contains nitrogen and hydrogen only. If the producer gas and water gas have been mixed in proper proportions, a mixture of nitrogen and hydrogen in the correct molecular proportions is obtained directly.

Hydrogen is chiefly produced by the various iron contact processes of decomposing steam; plants which utilise this process are supplied by the firm of Carl Francke, of Bremen, which uses the Messerschmitt process, and has erected plant with a total output of 68,000,000 cu. m. of hydrogen and 200,000,000 cu. m. of water

[1] *Zeitsch. d. Ver deutsch. Ing.*, 1900, p. 69.

gas per annum since 1914, and also by the Berlin-Anhaltischen Maschinenbau A.G., of Berlin, who use the Bamag-shaft process. Up till 1919 the Bamag supplied 76 orders, including many repeat orders, for a total of 120 water-gas plants for gas works, and 86 orders for 130 plants for industrial and aeronautical purposes, the daily output of plant supplied by them being 2,500,000 cu. m. Up to July, 1918, the Bamag had also supplied 75 hydrogen plants in execution of 47 orders and repeat orders, of an annual output of about 125,000,000 cu. m., among which were 18 plants for the B.A.S.F. works of a yearly output of 1·5 million cu. m. Large quantities of hydrogen are used for fat hardening, for the hydrogenation of naphthalene, the autogenous welding of metals, and so on.

The industry of liquefied gases [1] has developed to very large dimensions, largely through the growth of the nitrogen industry. Experience in handling such large quantities of gas has had a far-reaching influence on the apparatus and measuring devices of chemical industry in general.[2]

The nitrogen fixation industry very soon came under State control, in consequence of its importance for national defence, for agriculture, and for national food supplies. A survey of all the official regulations in this connection is unnecessary, and a few price data given in the table on pp. 90–91 will suffice. A distinction was at first made, as in the sale arrangements of the Ammoniak-V.-V., between District I., west of the Elbe, and District II., east of the Elbe. This division was abandoned later. The administrative order of January 11th, 1916, is more or less fundamental, as it introduces the idea of a kilogram percentage of nitrogen as the uniform price basis. The fertiliser dealers combined in 1915–16 to form the Deutsche Landwirtschaftliche Handelsbank G.m.b.H. of Berlin, which comprised 1,200 members in 1916, and which, jointly with the Bezugsvereinigung der deutschen Landwirte G.m.b.H. of Berlin, controlled the distribution of fertilisers sold by the Government. By an order of October 24th, 1917, a Price Fixation Bureau for cyanamide was established at the War Food Supply Office at Berlin, which was extended by a further order of March 13th, 1919, to include a Price Fixation Office for all nitrogenous fertilisers. This office imposed a levy, by means of which high manufacturing costs were subsidised and the various prices equalised. Producers were obliged to contribute to this levy, with which all home-manufactured fertilisers were debited. No further levies on nitrogenous

[1] Compare E. B. Auerbach, in Ullmann's "Encyclopædia," vol. v. (1917), p. 679.
[2] *Koppers-Mitteilungen*, 1919, parts 6 and 7.

PRICES OF THE PRINCIPAL NITRO

Date or Year.	Ammonium Sulphate. Ordinary Quality 25% NH_3	Ammonium Sulphate. Dried and Ground Quality 25 5% NH_3	Calcium Cyanamide (Nitro-Lime)	Sodium Ammonium Sulphate	Ammonium Chloride.	Ammonium Nitrate.
1913-14	Approx. M 28 per 100 kg		Per kg. % N = about M 1 16		.	..
1.6.1915	100 kg — M 30 50	District I. 100 kg — M. 31 00 District II 100 kg — M 31 50				
11.1 1916	Per kg % N I : M 1·48 II . M 1 49	Per kg % N I . M 1 48 II . M 1 50	Per kg % N I : M 1·47 II · M 1 47	Per kg % N I : M 1 48 II . M 1 49		.
5.6 1916	Per kg % N I and II as above	Per kg % N I M 1 51½ II M 1 52½	Per kg % N M 1 40			
16.3.1919	Per kg % N M 1 30 + package M 0 80	Per kg % N M 1 86 + package M 0 80	Per kg % N M 1 40 + package M. 1	Per kg % N M 1 80 + package M 0 80	.	Per kg. % N M 2 + package M 0 80
1 7 1919	Per kg % N M 2 90 + package M 1	Per kg % N M 2 96 + package M 1	Per kg. % N M 1 40 + package M 2	Per kg % N M 2 90 + package M 1	Per kg % N M 2 90 + package M 1	Per kg. % N M. 3 40 + package M 1
1.10 1919	Per kg % N M 2 90 + package M 2 50	Per kg % N M 2 96 + package M 2 50	Per kg % N M 1 40 + package M 3 45	Per kg % N M 2 90 + package M 2 50	Per kg % N M 2 90 + package M 2 50	Per kg % N M 3 40 + package M. 2 60
1.3.1920	Per kg % N M 9 50 + package M 2 50	Per kg % N M 9 85 + package M 2 50	Per kg % N M 1 40 + package M 9 30	Per kg % N M 9 50 + package M 2 50	Per kg % N M. 9 50 + package M 2 50	Per kg % N M 11 00 + package M 2 50
1.6 1921	Per kg % N M 14 50	Per kg % N M 14 85	Per kg % N M 12 90	Per kg % N M 14 50	Per kg % N M 14 50	.
10 10 1921	Per kg % N M 17 40	Per kg % N M. 18	Per kg % N M 15 50	Per kg % N M 17 40	Per kg % N M. 17 40	..
5 12 1921	Per kg % N M. 25 80	Per kg % N M 26 40	Per kg % N M 23	Per kg % N M 25 80	Per kg % N M 25 80	...
8.2 1922	M 29 80	M 30 60	M 26 50	M 29 80	M 29 80	.

REMARKS

District I.—Localities actually on the Elbe and west of the Elbe.
District II.—Localities east of the Elbe.
In terms of $NaNO_3$ the German price is now about one-half of the price on the world's markets.

GENOUS FERTILISERS IN GERMANY

Sodium Ammonium Nitrate.	Potassium Ammonium Nitrate.	Sodium Nitrate.	Bonemeal-Ammonium Nitrate.	Gypsum-Ammonium Nitrate or Calcium Ammonium Nitrate.	Ammonium Sulpho-Nitrate.	Various.
.	Chile nitrate, 100 kg. = M. 22 20		..	..	..	.
		..	.	...	.	..
		..		.		Bonemeal. Per kg. % N M. 2 10
..						
	Per kg % N M 2 20 + package M 0 80	Per kg % N M 2 75 + package M 0 80				Per kg. % N, in bloodmeal, M. 2 60, in hornmeal, M. 2 20
Per kg % N M 3 40 mixed with 40–45% common salt, + package M 1	Per kg % N M 3 40 Manufactured from ammonium nitrate and potassium chloride In addition per kg % H_2O - M 0 48 + package M 1	Per kg % N M 3 40 + package M 1	Per kg % N M 3 40 Mixed with at least 3% bonemeal, + package M 1	Per kg % N M 3 40 Mixed with about 40% gypsum or lime, + package M 1	(Added later) Per kg % N M 3 30 + package M 1	Per kg % N in bloodmeal, M 2 60; in hornmeal, M. 2 20
Per kg % N M 3 40 Common salt, M 1, and for mixing M 2 per 100 kg of product + package M 2 60	Per kg % N M 3 40 Potash freight, mixing, etc, M. 3 50 per 100 kg + package M 2 60	Per kg % N M 3 10 + package M 3 10	Per kg % N M 3 40 Bonemeal, M 0 60, mixing M 2, per 100 kg of product + package M. 2 60	Per kg % N M 3 40 Gypsum or calcium carbonate, M 1 mixing M 2, per 100 kg of product + package M 2 60	Per kg % N M 3 30 + package M 2 55	Per kg % N in bloodmeal, M. 2 60; in hornmeal, M 2 20
Per kg % N M 11 + package M. 2 50	Per kg % N M 11 + package M 2 50	Per kg % N M 13 50 + package M 2 50	Per kg % N M 11 + package M 2 50	Per kg % N M 11 + package M 2 50	Per kg % N M 10 50 + package M 2 50	Blood and horn meal as before. Bonemeal, per kg % N M. 6 (29.3 1920)
Per kg % N M. 14 50	Per kg % N M 14 50	Per kg % N M 17 50	Per kg % N M 14 50	Per kg % N M 14 50	Per kg % N M 14 50	Per kg. % N in bloodmeal, M. 2 60; in hornmeal, M. 2 20; in bonemeal, M. 2
Per kg % N M 17 40 with 40–45% common salt	Per kg % N M 17 40	Per kg. % N M 24	Per kg % N M 17 40 At least 3% bonemeal	Per kg. % N M 17 40 With 10% gypsum	Per kg. % N M 17 40	Bloodmeal, M. 19 Hornmeal, M 16
Per kg % N M 25 80	Per kg % N M 25 80	Per kg % N M 31 20	Per kg % N M 25 80	Per kg % N M 25 80	Per kg % N M 25 80	Bloodmeal, M 19
M. 29 80	M. 29 80	M 36	M 29 80	M 29 80	M 29 80	Hornmeal, M. 16

fertilisers have been called for since June 1st, 1921. The table presents a good summary of the various qualities of fertilisers which were dealt with, and shows that prices were quite normal until the middle of 1919, but rose rapidly from July 1st, 1919. The maximum price is understood free on rail at any German normal gauge railway station, excepting in the case of bloodmeal and hornmeal, in which the conditions are free on rail at the producing works. On resale the following amounts per 100 kg. may be added to the maximum prices :—

(*a*) Up to 1 mark for quantities less than 5 tons.

(*b*) Up to 1·70 mark if the goods are sold at or despatched from store.

(*c*) Three per cent. of the total invoice amount.

The producer has to allow the dealer a discount up to 3 marks per 100 kg. of material. When nitro-lime is delivered in sacks, the gross weight is invoiced. If 50-kg. packages are called for, a charge of 25 pfg. may be made for each paper package. The production of mixed fertilisers is controlled by special rules and ordinances. Imported mixed fertilisers from abroad or from the occupied territories are also subject to these maximum prices (Order of May 4th, 1920). The control of prices, deliveries, and so on, is now regulated by the publications of the Imperial Board of Trade or by the Board of Control for Ammoniacal and Phosphatic Fertilisers in Berlin. A new factor in German economic life has appeared in the form of a Nitrogen Commission, which meets from time to time and on which the Imperial Board of Trade, the Imperial Chancellery, the Federal States, the Nitrogen Syndicate, the various German agricultural unions, the dealers, the phosphate works, and the work-people are represented. Its duties are the fixation of sale prices, the control of the output and of sale conditions, the distribution of the output to agriculture and industry, the regulation of the imports and exports, and the distribution of information. The price increase of October 1st, 1919, was due to a decision of this commission, and was more especially designed to increase production.

The formation of this organisation, in which there were also represented the Imperial Chemical Trade Union, the Office for External Chemical Trade, and other organisations, rendered certain other bodies superfluous, which were formed during or shortly after the War. Among these were the Reichskommissariat für Stickstoffwirtschaft (Imperial Commission for the Nitrogen Industry) founded in 1917 by the War Office for the distribution of nitrogen compounds for munitions, which was under the supervision of Dr. Bueb, the Imperial Department for Economic Demobilisation (Chemical

Group) (Chairman, Professor Haber), the Sub-Committee for the Fertiliser Industry, the Central Office for the Promotion of Fertiliser Manufacture, and others. These were therefore dissolved. Freight charges for fertilisers were frequently revised during 1919 and 1921.

In the spring of 1915 the only synthetic nitrogen works in Germany, apart from the Oppau Works of the B.A.S.F., were cyanamide (nitro-lime) works. The nitro-lime producers attached to the group of the Deutsche Bank are said to have used this circumstance to suggest to the Government the formation of a nitrogen monopoly. They hoped by this means to ensure higher prices and larger returns from their expensive plants.[1] The Reichstag was induced to consider a Bill authorising the introduction of a nitrogen monopoly[2] which was carefully considered by a special commission, which considered evidence by no less than thirty experts. Various bodies considered this scheme, including the Committee of the Association for Promoting the Interests of the German Chemical Industry, and a deputation from the "Altesten der Kaufmannschaft" (Elders from the Merchant Community) of Berlin; memoranda were received from the Chambers of Commerce of Frankfort-a.-M. and Hamburg, and other very informative memoranda from the B.A.S.F., the Chem. Fabrik vorm. Weiler ter Meer, and the Union of German Fertiliser Manufacturers.[3] The B.A.S.F. in particular made it perfectly clear that the monopoly would essentially form a protection for the nitro-lime industry, which was working at a loss, whereas they themselves would very shortly be able to supply any required quantity of ammonia more cheaply without any State support. The *Nordd. Allgem. Ztg.*, a semi-official organ, then wrote as follows, in order to dissipate any doubts with regard to the desirability of the proposed monopoly: "The conclusion that the proposed monopoly was essentially designed in the interests of the nitro-lime producers is erroneous. The actual purpose of the proposal is to ensure a sufficient production of nitrogen compounds of any kind to supply domestically all possible military and economic national requirements. The assumption that the national Government, in framing its policy, has left out of account the Haber process of manufacturing ammonium sulphate synthetically, and has mainly relied on the Caro process of manufacturing nitro-lime, is also erroneous. In actual fact the Government secured an acceleration of the development and the considerable enlargement of the plant working according to Haber's process by very extensive financial co-operation

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 154–155.
[2] *Chem. Ztg.*, 1915, p. 200; *Chem. Ind.*, 1915, Nos. 23–24.
[3] *Chem. Ztg.*, 1915, p. 372.

before the agreements with the nitro-lime group were ever concluded."[1] During the proceedings of the Commission, the Secretary of State, Helfferich, emphasised the fact that powers were desired for a monopoly of the wholesale trade only, without restricting the retail trade, and that price increases of nitrogen compounds were to be excluded. At their meeting of August 20th, 1915, the Commission unanimously passed a resolution that they were ready in principle to agree, in case of need, to a law authorising a trade monopoly of nitrogen.[2] Although the "Ständige Ausschuss des Deutschen Landwirtschaftsrates" (Permanent Committee of the German Agricultural Council) assented to the acceptance of this Bill with certain reservations,[3] it was finally abandoned, owing to the above-mentioned objections.

All intentions of establishing a monopoly thus appeared to have been disposed of.[4] The public were all the more surprised when it was announced on April 10th, 1919, that the Government had been conducting negotiations with the producing groups for some time under the direction of the Imperial Exchequer, in order to establish a nitrogen syndicate (Weimar Report of April 10th, 1919, in *Vorwärts*). Several references to the danger of such a monopoly had already appeared in trade journals.[5] The German Government laid their plan before the National Assembly, the Economic Committee of which studied it in detail on April 10th, 11th and 12th, 1919. We quote here from the report of the proceedings by the *Magdeburgische Zeitung*, No. 275 (evening edition of April 12th, 1919), according to which, wishes were expressed for the fixation of a suitable relation between the prices of fertilisers and the agricultural benefit to be derived from them. Objections were made by Deputy Dr. Maier (Swabia), who remarked that the price of fixed nitrogen should be regulated according to the results of those works which were technically most advanced and which were working on the most profitable basis, and not according to the working costs of obsolete works in which the Government might happen to be interested. Objections were also raised by several other deputies. In reply, the Minister, Gothein, asked[6] that the Government should not be pressed further, as understandings had been arrived at with the interested parties after negotiations which had lasted for months as a basis for the proposed agreement. There was no intention of

[1] *Chem. Ztg.*, 1915, p. 439.
[2] *Ibid.*, 1915, pp. 404, 653.
[3] *Ibid*, 1915, p. 768.
[4] *Zeitsch. f. angew. Chem.*, 1918, iii., 62.
[5] See *Zeitsch. f. angew. Chem.*, 1918, iii., 613; *Weltwirtschafts-Ztg.*, 1919, No. 16.
[6] *Zeitsch. f. angew. Chem.*, 1919, ii., 266.

continuing indefinitely uneconomic manufacture in the Government works. Nothing could be said about the future course of prices, in view of the present price of coal (April 12th, 1919) and the uncertain labour situation. When the prices of coal and food had dropped, the prices of fertilisers would also be reduced. Whether this price could be brought into definite relation with the price of agricultural products could not be foretold. The Government was itself very greatly interested in a rapid supply of fertilisers to the agricultural industry. Such a supply was, however, rendered very difficult by the bad transport conditions. The Economic Committee was ultimately unanimously satisfied with the agreement with the syndicate, and passed by a large majority three resolutions concerning the fixation of prices, rapid deliveries of nitrogen products to agricultural interests, and finally the representation of groups of consumers in the syndicate.

A detailed article in the *Berliner Börsen-Courier* of April 19th, 1919, illustrates the lively general interest in these important projects; it will be quoted here, as it represents a valuable new standpoint regarding the reasons leading to the establishment of the syndicate: "When introducing the Enabling Bill of 1915, the Government was rightly able to insist in the Reichstag that the proposal had neither a private economic nor a fiscal motive, but had essentially been framed from the standpoint of national defence; now (in April, 1919) this standpoint is no longer valid. If, therefore, one seeks for reasons for the formation of the new syndicate, one will not be in error in assuming that the State is now concerned in the protection of its investments, which amount to over 100,000,000 marks, and also in the security of the advances which it has made to the B.A.S.F. The B.A.S.F. cannot be the motive force in the formation of the combine, as in actual fact it produces nitrogen compounds much more economically than the nitro-lime factories. It should, however, derive considerable benefit from the formation of the syndicate, as it has been assured of a 60 per cent. proportion of the sales, and, moreover, the prices would have to be regulated according to the average very high production costs of the nitro-lime factories. It has, therefore, no further interest in persisting in its former opposition."

The coke ovens and gas works may have been guided by similar considerations. Their production costs are extremely small. As the ammonia produced by them is essentially a by-product, the production cost is essentially a matter of book-keeping. It must therefore be assumed that the formation of the syndicate was actually carried out to protect the nitro-lime manufacturers who

have joint interests with the Imperial Government. In the interests of national economics, it is therefore very deplorable that the Government works were erected to work an obviously unprofitable process. The consequence is that our agriculture has now to pay much higher prices for nitrogenous fertilisers than would be the case under free competition. It is also to be feared that new inventions might be retarded or stifled by the syndicate. If, therefore, the formation of a syndicate were really necessary, there should have been guarantees that the development of this young and promising industry should not be hampered. Having become the owner of enterprises which have become unprofitable through a mistake which cannot now be rectified, the Government should not allow itself to be misled by interested groups into taking measures which would tend to remove the advantage in the production of nitrogen compounds which we have, as compared with other states. This danger is, however, very real, for it must be considered probable that nitro-lime will not be able to compete with Chile nitrate without fiscal protection. The provision of nitrogen compounds for our industry and agriculture cannot, however, be effected by our own works unless we succeed in reducing the price to a point appreciably below that of Chile nitrate. It would also be impossible to export the surplus production if the domestic production costs were so high that competition with foreign products were hopeless.

The danger of an international nitrogen trust has in no way disappeared. If the export tax of about 35 pfg. per kilogram of nitrogen established in Chile before the War, which furnished almost the whole of the public revenue of the Chilean State, were suddenly removed, the price of Chile nitrate would undoubtedly sink below the German nitrogen prices. In view of the tendency to the formation of a trust which has always characterised the Chilean nitrate industry, which is mainly supported by American and British capital, there is a considerable possibility that the old plan for the formation of a nitrate holding company, which would include the large American and English nitro-lime producers, may reappear. The very fact that we are ahead of foreign countries in the industry of nitrogen fixation renders it not improbable that this plan of defence against German competition may be assisted with the help of greater political power. We should therefore avoid all measures which might in any way render our production, which is at present on a competitive basis, more expensive. Such an effect would, however, ensue if the formation of the syndicate resulted in prices which were fixed according to the average cost of production of the nitro-lime factories, and not according to the most economical methods of production. The

interests of the revenue are not so important that their protection by a syndicate is absolutely necessary.

On May 8th, 1919, the three large groups of manufacturers of nitrogenous fertilisers united to form a syndicate, namely :—

(1) The B.A.S.F.

(2) The Deutsche Ammoniak-Verkaufs-Vereinigung in Bochum, with the Oberschles. Kokswerken und Chem. Fabriken A.G., and the Wirtschaftliche-Vereinigung deutscher Gaswerke in Cologne.

(3) The nitro-lime industry represented by Bayrische-Stickstoff-werke.

The directorate of the syndicate, which has its seat in Berlin, consists of :—

Dr. Brückner, representing the Imperial Treasury; Dr. Bueb, representing the B.A.S.F.; Director Sohn of the Ammoniak-V.-V.; and Dr. Caro, representing the cyanamide industry.

The interests of the Government are therefore represented both financially and on the directorate.

The Deutsche Stickstoffsyndikat G.m.b.H. has its business address at Berlin, N.W. 7, Neustädtischekirch Str. 9. It was founded with a capital of about 360,000 marks, of which about 110,000 marks are held by the Government, 150,000 marks by the B.AS.F., about 50,000 marks by the cyanamide works, and a similar sum by the coke and gas works. After the extension of all the works, a maximum domestic production of 500,000 tons of nitrogen per annum is contemplated, which will be divided as follows :—

300,000 tons nitrogen from the B.A.S.F.
100,000 tons nitrogen from the cyanamide works.
100,000 tons nitrogen from the coke ovens and gas works.

This production compares with a total peace-time consumption in 1913 of about 222,500 tons of nitrogen, and its enormous value is evident if one assumes, for instance, the maximum prices of March 1st, 1920. The B.A.S.F. production must then be valued at an average of 13 marks per kilogram of nitrogen, the cyanamide production at an average of 10·70 marks per kilogram of nitrogen, and that of the coke ovens and gas works at 12 marks per kilogram of nitrogen. The values for the annual production are thus :—

	Marks.
B.A.S.F.	3,900,000,000
Nitro-lime works	1,070,000,000
Coke ovens, etc.	1,200,000,000

The organisation of the nitrogen syndicate was further described by Dr. Bueb in *Chemische Industrie* of November 25th, 1919.[1] According-

[1] *Zeitsch. f angew. Chem.*, 1919, ii., 807.

ing to Dr. Bueb, the production of cyanamide in October was increasing so satisfactorily that the production for the month was 25,000 tons of nitrogen. Had Germany been victorious in the War, a maximum production of 500,000 tons of nitrogen would have been attained at about the commencement of 1920. The revolution completely changed the situation, and a recovery only asserted itself gradually. This led to difficulties in the distribution of the continuously increasing production in 1920–21, according to an announcement of the Nitrogenous Fertiliser Committee.[1] A control office for ammoniacal and phosphatic fertilisers was established in Berlin, W. 8, for the special purpose of controlling deliveries from works which did not belong to the syndicate. This controls deliveries from the Deutsche Ammoniak-V.-V., the Oberschlesischen Kokswerken A.G., and from Wirtschaftl. Vereinigung Deutscher Gaswerke (Industrial Association of German Gasworks). Production statistics have to be submitted to this control office every month, and it regulates inland deliveries and works consumption of all producers, and definitely ensures that 50 per cent. of the production is supplied direct to agriculture and 50 per cent. to "trade." A fertiliser committee acts in conjunction with the syndicate, and the membership of this committee has already been given here; a representative of the Imperial Food Supply Office has been added.

In the article already mentioned, Bueb shows that the proportion of nitrogenous compounds supplied by the gas works has fallen from 18 per cent. before the War to 5 per cent. to-day. It is intended that in future the gas works shall still supply ammonium sulphate and also sufficient concentrated ammoniacal liquor for the ammonia soda works. The manufacture of pure concentrated aqueous ammonia and pure ammonium salts is to be confined exclusively to the B.A.S.F.

The syndicate no longer entertains the idea of an absolute Government monopoly, and only deals in fertilisers, whilst such nitrogen products as are used industrially are subject neither to fixation of a maximum price nor to supervision by the syndicate. The activities of the syndicate started on August 1st, 1919.

According to the Peace Treaty of Versailles, monthly deliveries have to be made to France of 2,500 tons of ammonium sulphate at a price from October to December, 1920, of 142 fr. per 100 kg. carriage free to the French frontier, or 147 fr. in strong new sacks. In 1920 the first attempts were made to export large additional quantities of nitrogen compounds in order at least to stabilise the inland prices if not to reduce them. The Economic Committee of the Reich-

[1] *Chem. Ztg.*, 1920, p. 404.

stag decided in August, 1920, to allow 25,000 tons of nitrogenous fertilisers to be exported in the first instance. These deliveries, the utility of which has been seriously contested, were mainly supplied by the Leuna works. The main intention of reducing the inland price was not achieved. In order to increase the somewhat heavy home demands, the Stickstoffkredit G.m.b.H. was founded in January, 1921, with 500,000,000 marks share capital, of which 25 per cent. was paid up. Most of the shares of this credit organisation have been taken up by the nitrogen syndicate. Other shareholders are the Deutsche Ammoniak-Verkaufsvereinigung of Bochum, the Oberschlesischen Kokswerke und Chemischen Fabriken A.G., the B.A.S.F. and the Bayr. Stickstoffwerke. When supplying nitrogenous fertilisers, the nitrogen syndicate only draws half the purchase price, and the rest is paid in the form of bills, which it disposes of through all supply and credit organisations and the Stickstoffkredit G.m.b.H., which are to have the power of discounting these through the Reichsbank and private discounting firms. Arrangements have been considered for combining the control of the grain trade with that of the supply of fertilisers, by means of an organised form of barter.

The following table shows the nitrogen contents of the various fertilisers mentioned in the list of maximum prices :—

	Per cent. N.
Ammonium sulphate	20·5 to 21
Cyanamide	18 ,, 20
Sodium ammonium sulphate . about	10
Ammonium chloride	25
Ammonium nitrate	33 to 35
Sodium ammonium nitrate . .	20
Potassium ammonium nitrate .	16
Sodium nitrate	15·6 to 16
Bonemeal ammonium nitrate . about	30 ,, 32
Gypsum or lime ammonium nitrate	20·5 ,, 25
Ammonium sulpho-nitrate . .	27

These figures can naturally not be considered as standard values, as the composition of the mixed fertilisers may differ from those implied in the above table. Urea, which contains 46·6 per cent. of nitrogen and ammonium bicarbonate, are not included in this table, as no considerable demand for these products exists at present. Both have an undoubted future as fertilisers, in consequence of the high nitrogen contents and complete absence of useless foreign constituents. Ammonium nitrate, which is a main product of the synthetic methods, is unsuitable for delivery in quantities, on account of its hygroscopic character. Apart from other incidental disadvantages, briquetted material, although it may be of industrial

use, is less suitable for agricultural purposes, as it would be necessary to disintegrate it before use. The more modern mixed fertilisers, more particularly potassium ammonium nitrate and ammonium sulpho-nitrate, which are produced by combining ammonium nitrate with potash salts or ammonium sulphate, are not hygroscopic, and do not possess the explosive character of pure ammonium nitrate. The admixture with ammonium nitrate of potash salts, bonemeal, gypsum, or powdered limestone offers a double advantage ; it not only ensures the addition to the soil of a further fertilising element other than nitrogen, but also reduces the nitrogen contents of pure ammonium nitrate, which are rather high, to the usual standard of about 20 per cent. Mixtures of common salt with ammonium nitrate are possibly less to be recommended. Since the end of 1920 pure ammonium nitrate has been struck off the list of fertilisers, and may no longer be dealt with as such.

Apart from chemical and other technical considerations, the composition of mixed fertilisers is guided, on the one hand, by the desirability of avoiding too high a percentage of nitrogen, and, on the other hand, of maintaining it at a sufficient height to ensure favourable transport conditions. The farmer bases his supposed fertiliser requirements on the older fertilisers, Chile nitrate, ammonium sulphate, or cyanamide. Therefore, the new fertilisers must, to some extent, correspond in nitrogen contents with these. On the other hand, the higher the nitrogen content the lower are the percentage freight charges. Allowing for both these considerations, ammonium sulpho-nitrate may, perhaps, be considered as the most favourable mixed fertiliser at present available. The fertilising effect of ammonium nitrate is very favourable, in so far as the nitrate nitrogen is rapidly assimilated whilst the ammoniacal nitrogen acts more slowly and over a longer period. On the other hand, the excessive solubility in water is a disadvantage, as the salt is washed out of the soil by rain before it has been able to exercise any fertilising action ; this solubility is slightly reduced by the addition of potash salts, ammonium sulphate, etc. The percentage of nitrogen in ammonium nitrate, which is more than double that in Chile nitrate, led the farmer, unconsciously, to over-fertilise his fields, very often with very serious consequences. These facts led to the production of mixed fertilisers, of which potassium ammonium nitrate, especially, is referred to in the trade as "mixed salt." Ammonium chloride is produced by the B.A.S.F. by the Solvay process, but has not yet been sold in large quantities. Propaganda for these new fertilisers is carried on by the advisory stations already mentioned, controlled by the B.A.S.F., in Cassel, Munich, Ludwigs-

hafen, etc. Sodium ammonium nitrate is produced by the interaction of ammonium nitrate and sodium chloride; half of its nitrogen is present in the form of ammonium chloride and the other half in the form of sodium nitrate. Potassium ammonium nitrate is obtained by the interaction of potassium chloride and ammonium nitrate, and contains 23 to 25 per cent. of potash.

It is unnecessary to explain here how the fact that the natural return of the nitrogen from the plant to the soil, in the form of manure, no longer occurs to a sufficient extent when the soil is intensively cultivated, led to the development of Liebig's teaching in practice.[1] It will suffice to reproduce the figures of Bueb [2] on the increase of the crop per ton of nitrogen, which is introduced into the soil in the form of fertiliser. Per ton of nitrogen, the increases are :—

18 tons of wheat grain	+	40 tons of wheat straw.
24 tons of barley grain	+	30 tons of barley straw.
24 tons of oat grain	+	34 tons of oat straw.
129 tons of potatoes	+	40 tons of potato foliage.
150 tons of sugar beet	+	199 tons of sugar beet foliage.
240 tons of fodder turnip	+	79 tons of fodder turnip foliage.

N. Caro also came to the conclusion that each ton of nitrogen increases the yield of grain by at least 20 tons, and that of potatoes by at least 100 tons,[3] and that an increase in the German production of nitrogenous fertilisers is, therefore, a primary necessity for the German nation. The following small table shows how badly German agriculture was supplied with fertilisers.[4] The deliveries in tons were :—

	N.	P_2O_5.	K_2O.
May 1st, 1913, to April 30th, 1914 .	210,000	630,000	557,450
(And, in addition, 40,000 tons of nitrogen for industrial purposes.)			
May 1st, 1917, to April 30th, 1918 .	92,334	325,800	779,000
May 1st, 1918, to April 30th, 1919 .	115,000	230,000	670,000
May 1st, 1919, to April 30th, 1920 .	158,000	147,000	756,000
May 1st, 1920, to October 31st, 1920	83,000	100,700	202,000

In these circumstances, the serious position of agriculture, which was repeatedly described in gloomy terms at the annual gatherings of the German Agricultural Society, is only too easily understood.[5] Now that the nitrogen industry has developed so satisfactorily that normal deliveries may be anticipated, further developments are endangered by the prospect of excessive prices. At the eighty-eighth meeting of the Fertiliser (Kainite) Section of the German

[1] Schweiz, *Apoth-Ztg.*, **57**, 691; *Die Technik i. d. Landwirtschaft*, 1920, part 5, pp. 260 *et seq.*

[2] *60th Jahresvers. des deutsch. Ver. von. Gas. u. Wasserfachmannern*, 25–26, September, 1919; *Chem. Ztg.*, 1919, p. 712.

[3] Voss, *Ztg. Abendblatt*, 11 Dec., 1919; *B. Z. am Mittag*, **72**, April 2nd, 1919.

[4] *Zeitsch. f. angew. Chem.*, 1919, ii., 360; 1920, ii., 410; *Umschau*, 1919, p. 157.

[5] *Chem. Ztg.*, 1919, pp. 161, 252; *Zeitsch. f. angew. Chem.*, 1919, ii., 158.

Agricultural Society, at Berlin, on February 19th, 1919, Professor Lemmermann, of Berlin, reported as follows :[1] "About 75 per cent. of German agricultural land is held by small and medium-sized holders, and was insufficiently supplied with nitrogen, especially before the War. This section of the agriculturalists will only be induced to utilise appreciably larger quantities of nitrogen if its price is reduced. All considerations with regard to profits on the manufacture at the works must remain a secondary consideration. It is also necessary that cyanamide should be supplied in a more readily utilisable form than before the War." Such experts as Professor N. Caro and the Under Secretary of State, D. Friedr. Edler v. Braun,[2] have shown that domestic agriculture can no longer utilise the home supply of fertilisers at their present prices, and that the importation of such foreign fertilisers as Chile nitrate, which occurred in the spring of 1920, must have still more deleterious effects in this direction.

The further development of the nitrogen industry must be strongly influenced by this position, though otherwise its prospects must be considered favourable, in view of the general shortage of nitrogen ; no over-production of nitrogen is to be feared for the present. An article by Edward John Russell, entitled "Artificial Fertilisers and their Immediate and Future Prospects," is of special interest.[3] Russell tabulates the quantities of fertilisers used in the principal consuming countries ; expressed in hundredweights of 50 kg. of nitrogen per hectare, they are :—

	Nitrogen	Total Artificial Fertilisers
Belgium	1·19	5·38
Luxemburg	0·168	4·05
Germany	0·44	3·31
Great Britain	0·40	1·78
Italy	0·074	1·19
France	0·047	1·133
Denmark	0·20	1·136

From these figures it is quite clear how very capable of extension is the use of nitrogenous fertilisers in Germany. We cannot, of course, consider the subject of agricultural chemistry in detail in this work, but may refer to the much-cited conclusions of the English chemist, Sir William Crookes. Crookes expanded his first lecture to a considerable treatise, entitled "The Wheat Problem" (1899), in which the important function of nitrogen in connection with food supplies is described at length. The fertilising value of the various

[1] *Chem. Ztg.*, 1919, p. 161.
[2] *Ibid.*, 1920, p. 88.
[3] *J. Soc. Chem. Ind.*, **36**, 250–261 (1917).

fertilisers varies, of course, considerably. According to the investigations of Gerlach, of Bromberg, for example, the efficiency of the nitrogen in ammonium sulphate, is on the average, only 89 per cent., and of that in cyanamide only 76 per cent. of the efficiency of the nitrogen in Chile nitrate.[1] It must, however, be remembered that the action of cyanamide continues until the next harvest. The questions circulated by the German Agricultural Society resulted in an expression of opinion which was, on the whole, satisfactory as to the efficiency of cyanamide. The difficulties of applying this fertiliser have not yet been fully overcome. The quality containing mineral oil has an equal fertilising value, but the improvement comprised in absence of dustiness diminishes after a short time. Good drilling machinery is to be recommended, as is also admixture with basic slag or with potash salts immediately before application. Granulated cyanamide has a lower fertilising value. It is important that cyanamide should be applied to the soil at least two to three weeks before the crop is sown, in order to afford the nitrogen an opportunity of being converted into ammonia and into nitrate. When used as a top dressing for winter crops, cyanamide must be applied as early as possible, in January or February, and may be used even during light frosts. The usual dressing is 2 to 4 cwts. per hectare; it has proved satisfactory, more especially as an autumn manure for wheat, but can also be used for barley, as it acts less intensively than nitrate, and consequently produces a brewers' barley containing less albumen. In some cases it is as effective as nitrate. It acts most favourably on good medium soil, whereas it is less satisfactory on sandy, mouldy, or peaty soil.[2]

The nitrogen in ammonium sulphate must also be converted into nitrate nitrogen by the action of nitrifying bacteria in the soil, before it can be assimilated by the plant. In general, the plant only assimilates nitrate nitrogen. It is true that ammoniacal nitrogen can be absorbed directly by the root, but it suffers from the disadvantage that it is absorbed by the particles of soil and humus, whereas nitrate nitrogen is always freely mobile in solution in the soil water, and is carried by this latter to the root of the plant. This fact explains the extraordinarily rapid action of nitrate, which causes meadow grass to shoot up luxuriously, and also leads to a greatly increased output of foliage and straw in the case of other agricultural products. Nitrate nitrogen is generally used where the growth of the plant is to be accelerated—for example, as a dressing

[1] *Chem. Ztg.*, 1915, p. 764.

[2] See Möller and Seidler, on artificial fertilisers ("Kunstliche Dungemittel"), in Ullmann's "Encyclopædia," vol. iv., pp. 223 *et seq.*

for winter wheat. Turnips give a very good return for the use of nitrate, but, on the other hand, barley does not assimilate nitrogen well, and the potato is very sensitive to fertilisation by nitrate. Large additions of nitrate easily cause wheat to lodge.

The effect of ammonium sulphate will naturally be most satisfactory where the soil and other conditions—such as air, water, moisture, bacteria and lime—are favourable to its conversion into nitrate nitrogen. It is, therefore, far more suitable for humid, well aerated, warm soil, with a medium content of moisture and lime, than for cold, very wet soil containing but little humus and lime. Manuring with ammonium sulphate does not produce the luxurious growth which is obtained with nitrate, but, on the other hand, produces firmer and more appetising crops, containing less moisture, qualities which are very advantageous for the growth of vegetables. It is also more firmly held by the soil, and it is not so readily washed out as Chile nitrate. Acid, peaty soils are entirely unsuitable for ammonium sulphate, which, however, is particularly recommended for loamy and sandy soils and also for very permeable sandy soil. Winter crops are given the following quantities in autumn before the sowing :—

	Lbs. per rod.
Winter wheat	15 to 30
Winter barley	10 ,, 25
Winter rye.	15 ,, 35
Winter rape	25 ,, 40

As early as possible in February or March the remainder is applied as a top dressing, which may even be applied over a light covering of snow, in the following amounts :—

	Lbs. per rod
Winter wheat	35 to 95
Winter barley	25 ,, 40
Winter rye.	25 ,, 65
Winter rape	55 ,, 85

For manuring summer root and grain crops ammonium sulphate is applied at latest when sowing. The amounts required in pounds per rod are :—

Summer barley	35 to 75
Oats	50 ,, 100
Fodder turnips . . .	150 ,, 250
Sugar beet	125 ,, 200
Potatoes.	100 ,, 150
Meadows and grazing land .	50 ,, 125

The action of the newer fertilisers may be gathered from the peculiarities of the action of nitrate and ammonia nitrogen. In the

case of ammonium nitrate the nitrate nitrogen acts at once and the ammonia nitrogen more slowly, so that this fertiliser offers a peculiarly useful combination. Fertiliser trials with calcium ammonium nitrate, which were communicated by Professor Hoffmann in the Proceedings of the German Agricultural Society, gave favourable results, but the inclination is noted for this fertiliser to become hard and to form lumps.[1]

The fertilisation of forest land has recently become more important, but can only be shortly referred to here. Oak plantations require, per hectare, 1,000 to 1,600 kg. of kainite, 1,000 to 1,600 kg. of basic slag, and 100 to 200 kg. of Chile nitrate.[2]

According to Ost, average crops annually remove the following amounts of fertilising elements in kilograms per hectare :—

	P_2O_5	N	K_2O
Rye	25	65	50
Sugar beet	35	60	150
Potatoes	30	95	100
Hay	35	95	100

These amounts should be replaced in any rational scheme by manuring. The general introduction of artificial fertilisers and the intensive cultivation of the soil has led to very satisfactory increases in the yield, as is shown by the following table :—[3]

Average Harvest in Germany in Tons per Hectare

	Beginning of the 19th Century	1879-85.	1884-88	1889-93.	1894-98	1899-1903	1904-08	1911	1912.	1913
Wheat	1·028	1·26	1·36	1·39	1·54	1·87	1·98	2·08	2·26	2·35
Rye	0·862	0·93	1·00	1·05	1·19	1·50	1·63	1·78	1·86	1·92
Barley	0·800	1·29	1·30	1·31	1·43	1·85	1·89	1·99	2·19	2·22
Oats	0·564	1·09	1·18	1·15	1·31	1·74	1·82	1·78	1·95	2·19
Potatoes	—	8·00		—	—	—	-	10·35	15·30	15·86

By contrast we have the lamentable picture of the decrease in German harvests, without Alsace-Lorraine, in millions of tons since 1913 :—

	1913.	1914	1915.	1916	1917	1918	1919.	1920.
Rye	12·5	10·2	9·1	9·0	7·0	8·0	6·1	4·2
Wheat	4·4	3·8	3·75	3·0	2·2	2·4	2·17	2·2
Barley	3·5	3·0	2·5	2·3	2·0	2·2	1·9	1·7
Potatoes	52·8	44·7	52·3	24·6	34·4	29·4	21·5	28·2
Sugar beet	20·6	16·8	10·9	10·1	9·9	9·8	5·82	7·9

[1] See *Zeitsch. f. angew. Chem.*, 1918, iii., 488, 489.
[2] Pamphlet, "Kunstliche Dungung im Forstbetriebe"; see also *Forstwirtschaftl. Zentralbl.*, 1906; Schalk, *Dungeversuche in Forstgärten*, *Deutsch. Holzmarkt. u. Forstanzeiger*, June 30th, 1920, No. 53.
[3] Ullmann's "Encyclopædia," *loc. cit.*

Valuable statistics are given in the pamphlet "Grossmann-Bueb v. Flügge, Düngemittel im Kriege" ("Fertilisers in the War") (*Beiträge zur Kriegswirtschaft*, part 13, Berlin, 1917). These show, incidentally, that the annual loss of nitrogen caused by unsuitable storage and inefficient use of liquid farmyard manure was estimated to attain the value of 300,000,000 marks (1917). Therefore the attempts of M. Hoffmann, W. Gerlach and others, to discover a suitable method of preserving this material are of very great economic importance. It contains on the average :—

	kg N	kg P_2O_5	kg K_2O	kg CaO	Kg Organ Subst
1,000 kg. of fresh stable manure	4·5	2·0	6·0	4·5	210
1,000 kg. of fresh liquid manure	1·5 to 2·5	0·1	5·5	0·3	80

We cannot here consider the numerous special fertilisers—such as bacterial manures, chrysalis manure, artificial fertilisers from wool refuse, lime, gypsum, etc. (see *Chem. Ztg.*, 1919, 132, and *Tonind.-Ztg.*, 1918, 539), some of which only attained momentary importance. We must refer, however, to the extraordinarily important and interesting experiments on fertilisation with carbon dioxide, blast furnace gas, engine fuel gases, and so forth, which all represent attempts to utilise the energy of coal more completely.[1]

Some of my readers may consider that I am not justified in considering in such detail the agricultural chemical and fertiliser aspects of the nitrogen industry; but this book is primarily intended for those engaged in the industry, among whom there are so many wrong conceptions on these matters that it seemed advisable that I should consider them. I have embodied them in the historical section of this work, as they are closely connected with the development of the general situation in Germany, and must be taken into account in considering the future of the industry in that country. In this respect the B.A.S.F. have set an admirable example. As was announced by Bosch, at the annual gathering in 1918 of the Hallesche Verband für die Erforschung der Mitteldeutschen Bodenschätze und ihre Verwertung,[2] it established its own agricultural experimental station for experimenting with the new fertilisers; this includes about 1,000 experimental plots and 40 rods of trial plots. The company has also arranged for large field trials on a more extended scale.

[1] See *Chem. Ztg.*, 1919, pp. 449 *et seq.*, *Mitt. d. Deutsch. Landw. Ges.*, pp. 427, 451, 467, etc.; *Stahl. u. Eisen*, 1919, p. 1497; *Umschau*, 1919, p. 809; 1920, p. 265; *Die Technik i. d. Landwirtsch.*, 1920, pp. 401, 465–486; *Chem. Ztg.*, 1920, p. 247; *Zeitsch f. angew. Chem.*, 1920, ii., 224.

[2] *Zeitsch. f. angew. Chem.*, 1918, iii., 653.

The rapid development of the atmospheric nitrogen industry is not the least of the factors which have caused the erection of large power stations which more particularly serve the factories using the arc and cyanamide processes. The synthesis of nitrogen compounds is primarily based on water power in Upper Bavaria and on the presence of cheap lignite deposits in the Cologne basin and in Central Germany. The production of lignite in Germany has developed on an enormous scale. Whereas the production of coal in Germany increased from 127·8 million tons in 1906 to 192,000,000 tons in 1913, that is, by about 52 per cent. (7 per cent. per annum), the production of lignite during the same period increased from 47·9 to 87·1 million tons, that is, by 75 per cent. (by 10 per cent. annually). Whereas the coal production in 1919, which was 116·5 million tons, was considerably smaller than the peace-time production, which was 192,000,000 tons in 1913, the output of lignite has very greatly increased; it was 87·1 million tons in 1913, 100·6 million tons in 1918, and 93·8 million tons in 1919. The Central German district, which includes the districts around Cassel and Halle, Altenburg, Magdeburg, Niederlausitz, Frankfurt-a.-O., Forst and Görlitz, contributes about three-quarters of the total output:—

Lignite Production in Thousand Tons

	Germany	Rhineland	Mining District of Halle a/S
1913	87,116	20,256	46,502
1914	83,947	19,480	45,151
1915	88,370	20,788	47,718
1916	94,332	23,931	50,694
1917	95,535	24,218	51,659
1918 . . .	100,663	26,460	53,220
1919	93,800	24,380	65,543
1920	111,631	30,884	54,690

Lignite Briquette Production in Thousand Tons

	Germany	Rhineland	District of Halle a/S
1913	21,392	5,825	11,238
1914	21,272	5,444	11,312
1915	22,748	5,650	12,511
1916	24,061	6,121	13,018
1917	22,048	5,702	12,053
1918	23,111	6,014	12,202
1919	24,281	5,640	13,339
1920	24,277	6,661	12,264

This table[1] shows the influence of the large plant at Golpa-Zschornewitz (supplying the nitrogen works at Piesteritz), Leuna, etc., in augmenting the output of lignite in Central Germany, which will probably amount to 70,000,000 tons of crude lignite and 14·5 million tons of briquettes in 1920 and employ 130,000 workpeople; in 1919, 98,600 were employed. The profit on lignite production has, unfortunately, become smaller than ever.[2] The production figures per head per shift were as follows (in the Rhineland, 20,000 to 25,000 men were employed in 1919):—

	Central Germany.		Rhineland.
	Tons of Lignite.	Tons of Briquettes.	Tons of Lignite.
1914	4·70	1·50	15·69
1918 (third quarter) .	--	—	25·62
1918 (fourth quarter) .	--	—	17·29
1919 (first quarter) .	2·2	0·46	11·67
1919 (second quarter) .	--	—	12·48
1920	1·8	0·37	--

The average wages per shift in Central Germany were about 4·50 marks in 1914, and in the Rhineland 4·38 marks (communication from the Association of the Rhenish Lignite Industry at Cologne). In the second quarter of 1919 they were 15·30 marks, and to-day they have risen in the Central German lignite fields to about 36 marks. In peace-time the sale price per ton of crude lignite was 2·50 marks; to-day it is 66 marks, of which about 50 marks remain for the producer, after deducting the coal tax, the contributions to miners' homes and to the supply of food and the discounts. According to the accounts of fourteen of the most important German companies, which together produced 70 per cent. of the lignite production in these districts, the profits per ton of lignite were:—

	Marks.		Marks.
1913 . . .	0·44	1917 . . .	0·56
1914 . . .	0·40	1918 . . .	0·51
1915 . . .	0·41		
1916 . . .	0·51	1919 . . .	0·51

In 1913–14 these profits amounted to 17 per cent. of the sale price, but in 1919 to only 1 per cent. The position of lignite mining in Central Germany is rendered still more unfortunate when one considers the risk of flooding or fire, and also that the deposits in Central Germany proper will probably be exhausted in 50 to 100 years. As

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 142; *Metallborse*, 1921, p. 306.
[2] *Zeitsch. f. angew. Chem.*, 1920, ii., 257.

the nitrogen fixation interests are closely concerned in the future of Central German lignite mining through their two large undertakings at Piesteritz, near Wittenberg a.-E., and at Leuna, near Merseburg, their future appears to be in no way a happy one.

For a very short time the railway power station, Muldenstein, on the Bitterfeld-Wittenberg line, supplied the neighbouring nitric acid plants; the large power station of Golpa-Zschornewitz then became the centre of electric supply for the nitrogen fixation industry. At present the Golpa-Zschornewitz establishment is the largest complete steam power station in the world. It was described by Artur Fürst in two articles in the *Berliner Tageblatt*, Nos. 573 and 581, on November 8th and 12th, 1916. The Elektrowerke A.G. (Berlin) were founded in 1914–15 as a branch of the Berliner Elektrizitäts-Werke A.G., which belong to the A.E.G. The initial capital of the company was 5,000,000 marks; it took over the Golpa-Jessnitz lignite works and commenced the erection of a power station in March, 1915; this was carried out so rapidly that current could already be supplied on December 15th, 1915. During the business year 1916–17, 360,769,708 k.w.h. were supplied, namely, 307,387,000 to the Imperial Nitrogen Fixation Works at Piesteritz, 25 km. distant, over a high-tension transmission line, and 53,382,709 k.w.h. to the neighbouring electric nitric acid works at Zschornewitz, which were soon destroyed by an explosion (see p. 65). The transformation of a peaceful pine forest to an enormous modern power station was carried out with extraordinary rapidity. In this way the successive transformations of energy complete their cycle before our eyes; energy in the form of sunlight causes the growth of prehistoric forests in carboniferous times, and is stored underground for countless centuries in order to reappear in the form of electric energy, illustrating the law enunciated by Robert Mayer in 1842. Even in scientific and technical works large accumulations of figures have a tiring effect, but in this case they are necessary in order to obtain a clear idea of the size of this plant, which is so exceptionally important for our nitrogen fixation industry, and impresses the thoughtful passer-by with the fact that even modern technology is beautiful and poetical when viewed from the right standpoint.

From the lignite quarries at Golpa a double overhead transmission line carries trucks of 20 hectolitres capacity to the floor of the crushing mill. The cars are here emptied automatically into bins. The lignite is raised by enormous elevators into the bunkers of the boiler houses. The 4 boiler houses contain 64 boilers, each of 500 sq. m. heating surface. At present the consumption of lignite is 40,000 hectolitres—that is, about 6,000 tons per day, but this quantity can be increased

to 7,000 tons. The flue gases are removed by 9 chimneys about 100 m. high and of about 12 m. internal diameter below, and 4·5 m. above. Eight turbo-dynamos are designed for 22,500 k.v.a. each on the dynamo side, and 30,000 h.p. on the turbine side, that is, a total of 180,000 k.v.a., or 240,000 h.p. Water, which is pumped from the sump, is cooled by 11 condensing towers, each 35 m. high, through which 41,000 cu. m. of water may be passed per hour. The usual output is 100,000 kw. (see also H. Carl in *Volk und Zeit* and the illustrations in *Vorwärts* of September 21st, 1919). Further particulars will be found in articles by Professor G. Klingenberg, the constructor of the plant, in which plans and elevations will also be found.[1] Initially the kilowatt-hour cost only 1 to 1·5 pfg. Until the commencement of 1921, the city of Berlin paid 19·7 pfg. for the first 30,000 k.w.h., and 23·8 pfg. for quantities above that amount.

In August, 1917, the German Government acquired the shares of the Elektrowerke for 45,000,000 marks, by which means it commenced its commercial dealings in electric power. Piesteritz was supplied with three-phase current at 82,000 volts. After the discontinuance of the electric nitric acid works, the total capacity of the station could not be utilised by the Government nitrogen works, and therefore in 1918 a double overhead line, 132 km. long, was constructed to Berlin to transmit 30,000 k.w. at 110,000 volts. The branch line to Bitterfeld, which was constructed during the War, was extended in 1920 to the Gröbers Power Station, near Halle, by a company formed by the Government for operating the high voltage transmission system and named the "Gesellschaft für Kraftubertragung G.m.b.H." Gröbers is to be connected with large areas of the Province of Saxony, and will also supply Leipzig with 15,000 kw., and Magdeburg in 1922. By the connection of the various power stations by a ring main, the Province of Saxony will shortly be one of the most completely electrified districts of the German Empire. In the spring of 1921 the erection of a ninth turbine at Golpa was projected at a cost of 60,000,000 marks. The installation cost would raise the price of current in Berlin, for example, to an average of 42·2 pfg. instead of 22·6 pfg. as previously.

Since the end of 1919, the Imperial Treasury has also been interested in the Lower Silesian electrical supply industry, having acquired the power stations of Lauta-Senftenberg and Spremberg, which supply the aluminium works at Lauta and the carbide works. From these stations high-tension transmission lines are to be carried

[1] *Zeitsch. d. Ver. deutsch. Ing.*, 1919, pp 1081, 1113, 1145; and G. Klingenberg, "Das Grosskraftwerk Zschornewitz." Berlin, 1920.

to Dresden, to Saxony, and also to the province of Brandenburg and Berlin. The administration of these undertakings is allotted to affiliated companies, which are grouped together in the Industrial Division of the Imperial Treasury already referred to.

Similar enormous power stations have also been erected in the Rhineland lignite district not far from Cologne, more particularly the Vorgebirgs Power Station of the Rheinische Elektrizitätswerke in Knapsack, near Cologne, near which the Rheinische Elektrowerke has erected the Goldenberg Works, comprising large furnaces for the production of ferro-alloys. The Knapsack Works of the Gesellschaft für Stickstoffdünger adjoin the Rheinischen Elektrizitätswerke.

The Leuna Works also utilise current from lignite and so, to some extent, do the works at Oppau, whilst the nitrogen works at Chorzow in Upper Silesia are supplied by the power station of the Oberschlesischen-Elektrizitätswerke, which uses ordinary coal.

The following table gives the approximate cost of power before the War. 1 kw. then cost :—

In Central Germany, etc., from lignite .	1·0 to 1·5 pfg. (1-h.p. year, about 70 to 100 marks).
In Upper Bavaria, from water power	0·75 to 1·0 pfg. (1-h.p. year, about 70 marks).
In Sweden . .	0·6 pfg. (1 k.w. year, about 50 kr)
In South Norway .	0·3 pfg. (1-h.p. year, about 20 marks).

The present price in Germany of 1 k.w.h. from coal is about 15 to 20 times the former price. Now that high-tension mains traverse the whole country [1] and enormous power stations, numerous transformer houses and towers form a distinct feature in certain districts, the desire for more suitable and less disturbing arrangements of these technical works receives increasing attention.[2] The attempts to socialise the electric supply industry [3] have also had a prejudicial effect on the nitrogen industry.

It was necessary, in order to ensure the continued existence of the earliest methods of fixing atmospheric nitrogen, that electric technology should be greatly improved, more particularly that of the dynamos and of the electric furnaces.[4] During the War the production of carbon electrodes for the latter developed into a flourishing industry; (Siemens Brothers, at Berlin—Lichtenberg; Plania Works, at Ratibor in Upper Silesia; Gesellschaft für Teerverwertung, at Duisburg-Meiderich and Rauxel; C. Conradty, at Nürnberg, and at

[1] *Chem. Ztg.*, 1918, p. 255.
[2] W. Franz, "Werke der Technik im Landschaftsbild," Berlin, 1917.
[3] *Südd. Ind. Blatt*, 1919, p. 1991.
[4] *Chem. Ztg.*, 1918, p. 507; *Chem. Zentralbl.*, 1919, iv., 530, 1038, 1039.

Kolbermoor, near Aibling; and also the new Rheinische Elektrodenfabrik, which belongs to the Siemens-Stinnes group, at Knapsack, near Cologne).

Obviously, the utilisation of water power played a considerable part in the technology of atmospheric nitrogen on account of the large quantities of energy required. The cyanamide works at Trostberg and Waldshut, and the works at Rhina, at the confluence of the Murg with the Upper Rhine, all utilise water power. W. Halbfass gives detailed data on the water powers of Germany, the total of which is quite considerable, though they in no way compare with the potential water powers of other states. According to Halbfass, the total water powers in Germany amount to about 11·4 million horsepower. In Bavaria, about 20 per cent. of the available horse-power could readily be exploited, and 30 to 40 per cent. in the rest of Germany, amounting together to about 4,000,000 h.p.[1] In Germany, in 1910, less than 5 per cent. of the total mechanical power was produced by water power, whilst in France the proportion was already 40 per cent. According to the latest views, it is possible to exploit larger amounts of water power in Germany than was formerly supposed. About 470 cu. km. of water are available. Of this quantity about 20 cu. km. are flowing water, about 50 cu. km. represent standing water, and the enormous remainder of 400 cu. km. is present as soil water. Apart from the numerous water power associations which are concerned with comparatively limited areas, the control and utilisation of German water power is mainly carried out by the Wasserkraft G.m.b.H, of Berlin, and the Deutsche Wasserkraftverband, of Berlin-Charlottenburg.[2]

The development of the large power resources of the Upper Rhine and of Bavaria is particularly important.[3] The question of the Alz especially concerns the nitrogen industry and will, therefore, be considered in somewhat greater detail.[4] The Alz is the northern outlet of the Chiem Lake, and is really the northern continuation of the Tiroler Ache, which flows into the south side of the Chiem Lake. The Chiem Lake is very large, having an area of 80 sq. km., and forms an ideal storage for regulating the flow of the Alz, which is very irregular. Unfortunately nothing whatever has so far been done to regulate this river. According to the height of the water, the Alz carries from 15 to 225 cu. m. of water per second. At Alten-

[1] *Wasser*, **13**, 115 *et seq.* (1917); *Zeitsch. f. angew. Chem.*, 1918, iii., 142; *Südd. Ind. Blatt*, 1919, p. 247; Koehn, *Zeitsch. f. d. ges. Wasserwirtsch*, 1919, p. 177.

[2] *Zeitsch. f. angew. Chem.*, 1919, ii., 111; *Chem. Ztg.*, 1919, p. 187; *Die Technik i. d. Landwirtsch*, 1920, pp. 372, 373; see also Binz, Leppla and Schwappach, "Waldbestände und Wasserkrafte," Brunswick, 1917.

[3] H. Dröse, "Die Ausnutzung der Wasserkräfte des Oberrheins," Karlsruhe, 1919.

[4] *Südd. Ind. Blatt*, 1920, p. 839.

markt, 70 km. north of the Chiem Lake, the Traun joins the Alz and increases its irregularity. Apart from floods, and a few very occasional droughts during heavy frost, the average flow of the Alz at low water is 25 cu. m. per second ; during a portion of the year, 40 cu. m. can be relied on, and 60 cu. m. per second for about six months. Immediately north of Altenmarkt is Trostberg, where the Bayrischen Stickstoffwerke established their works in 1908; 16,000 h.p. are here supplied by two falls of 5 and 19 m., in which the flow is 50 cu. m. per second. From the lower end of these falls at Tacherting to the Salzach at Burghausen, which enters about 6 km. east of the Alz, there is a natural fall of about 100 m. The plan was considered long ago of exploiting this fall by diverting the Alz into the Salzach at Burghausen, as in this way a water power of 60,000 h.p. would be obtained during six months, and 25,000 h.p. at low water. Unfortunately, the financial obstacles to this large scheme were insurmountable, so that the development is now being carried out in two stages. The upper stage, from Tacherting to Margarethenberg, has a fall of 37 m., and the lower, from Margarethenberg on the Alz, to Burghausen on the Salzach, 63 m. The latter project is being carried out by the Dr. Alexander Wacker-Gesellschaft für elektrochemische Industrie in conjunction with the Imperial Treasury,[1] under the name of Alzwerke G.m.b.H., Burghausen, and supplies 60 cu. m. of water per second and approximately 38,000 effective horse-power, which is to be utilised for the production of calcium carbide, which is in turn intended for the production of alcohol, acetic acid, etc.

The developments on the Alz were expected to be working by 1921 at latest. The concession for the Tacherting-Margarethenberg power development was obtained by the Bayrischen Stickstoffwerke, who began operations in 1916. At this point the Alz supplies about 22,000 effective horse-power at a flow of 60 cu. m. per second, and about 15,000 effective horse-power at 40 cu. m. per second at low water; at about 25 cu. m. per second it supplies 9,500 to 10,000 h.p. The Bayrischen Stickstoffwerke utilise from the Alz about 33,500 h.p. in all. The two upper power stages—I. at Trostberg, and II. at Tacherting—have been working since 1908, and the third at Margarethenberg started work in 1920. Immediately behind the outlet of the canal for the tail waters from power station II., near Tacherting, there is situated the weir of the canal supplying power station III. According to K. Martin, of Munich, the current which is developed is carried by 6 high-tension cables to 6 three-phase transformers, each of 3,000 k.v.a., in which it is stepped down to a

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 127 ; *Chem. Ztg.*, 1919, p. 270.

suitable voltage for the carbide furnaces. The carbide which is produced is crushed and carried in special cars on the works railway to the cyanamide works at Trostberg, where all the carbide produced at Tacherting and at Hart is nitrogenated. The power station at Margarethenberg produces an average of 115,000,000 k.w.h. per year, and the new carbide works at Hart produces about 30,000 tons of carbide. At Trostberg 9,000 to 10,000 tons of nitrogen can now be fixed annually, corresponding to about 60,000 tons of cyanamide.

The works at Margarethenberg and on the Alz are also used for supplying the net of transmission lines of the Bavarian overland

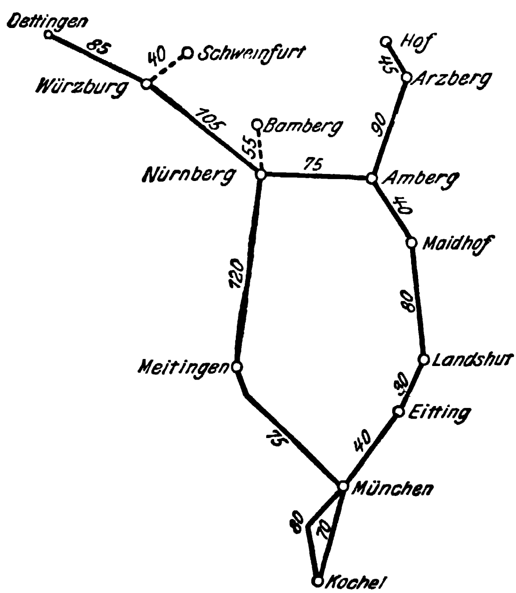

FIG. 2.
The numbers indicate distances in kilometers.

power stations. By its participation in the Alz development in 1918, the Government initiated its interests in the development of Bavarian water power. The plans for developing the Lower Isar from Landshut to the Danube, and of the Lower Inn, in which the Government is predominantly interested, have been postponed for the present for financial reasons, but are still the subject of continuous negotiations. These projects are not only connected with the future of the new aluminium industry, but also with the very large scheme of transferring the cyanamide industry, which was dependent on power from coal during the War, to this district.[1] Detailed negotia-

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 575.

tions have also been carried out by other parties relating to the utilisation of the Upper and Middle Inn (communication from the *Korrespondenz Hoffman*, November 2nd and 3rd, 1917).

On December 9th, 1918, Government works were also started in connection with the Walchensee[1] development to exploit the Walchensee and Kochelsee. The principal Bavarian electric power stations are to be included in the very large "Bayernwerk" (see Map, Fig. 2), which is to be formed into a joint stock company with 100,000,000 marks share capital, and with debentures of 400,000,000 marks.

In March, 1918, O. von Miller submitted his project to the Bavarian Landtag, and, after a lengthy consideration and financial support by the Imperial Government, this is now being carried out. After its completion, which, it is hoped, will be simultaneous with that of the Walchensee station, at the end of 1921, the Bayernwerk will represent the largest overhead power system in the world. A 100,000 volt ring main will pass from the Walchensee power station at Kochel (water-power) through Munich (water-power and steam), Eitting (power from the Middle Isar), Landshut (Lower Isar), Maidhof (lignite power-station), Amberg, Nürnberg (steam power, large power-station at Franken), Meitingen (works on the Lech, and steam) and Munich back to Kochel. A branch through Arzberg (power-station using Bohemian lignite) and Hof will connect with the electricity supply of Saxony ; another branch, with side lines, extends to Schweinfurt and Bamberg and the lignite power-station at Dettingen. Later the water power-station at Schongau (Lech) is to be linked up at Meitingen. At a meeting of the Bavarian Ministry of the Interior of December 3rd, 1919, Oskar von Miller stated that, in spite of greatly increased charges (the total constructional costs being 500,000,000 marks in the spring of 1921), the cost of power would still not exceed 3 to 4 pfg. per kilowatt hour. The main transmission system is 1,020 km. long.[2]

Bavaria disposes of a total of 2,000,000 to 2,500,000 h.p., capable of being developed, equal to 12,000,000,000 h.p. hours per year, of which 200,000 h.p. are already available ; 250,000 are being harnessed, and 700,000 h.p. are at the stage of projects or negotiations for concessions. According to a general distribution scheme, one-quarter of the total power, that is, 1,500,000,000 k.w.h., are to be supplied to works producing raw materials (smelting works, aluminium, carbide, nitrogen works, etc.), another quarter to electrification of railways, and one-half to be supplied to the various communities. If one

[1] *Südd. Ind. Blatt*, 1919, p. 2838.
[2] *Technik u. Wirtschaft*, 1919, pp. 71 *et seq.*

considers that power station I. at Höllriegelskreuth was already working in 1894, and that each horse power of water power saves one waggon of coal per annum, one is surprised that so far more has not been effected in this direction. In these times, which are much concerned with the conservation of raw materials, a wide field is open by these possibilities. The question of the socialisation of the water power has led to much discussion in Bavaria;[1] it is certain that the smaller industrially developed power schemes, more particularly, would be seriously affected by any such development, but, on the other hand, the right of the State must be acknowledged to secure more influence over the development of public water supplies than hitherto.[2]

In Bavaria the Upper Danube is at present almost completely exploited, but in Baden the Upper Rhine, in particular, is capable of considerable development, for which, however, international arrangements with the neighbouring States are necessary. A plan for the development of the waterfalls at Triberg provides for the production of 5,000 h.p.[3] The example of Württemberg shows that by combining numerous small water powers, a respectable total may be obtained.[4] In that state there are now 3,600 water-power developments which together supply 95,000 h.p. per annum on the average.[5] Almost 60 per cent. of these developments, of which 2,000 supply less than 10 h.p. and 1,200 less than 50 h.p., serve to drive corn mills and saw mills. The water-power authorities have elaborated a scheme, according to which 150,000 h.p. might be developed additionally in the whole of Württemberg by the construction of large dams, or a further 100,000 h.p. by a less ambitious scheme. At the price level of 1918, the construction of 15 of these works on the Neckar, and 5 on the Iller, which would together supply about 54,000 h.p., would cost about 1·7 pfg. in constructional charges per kilowatt hour. As against this, about 50,000 truck loads of coal would so be saved per year. Six thousand h.p. are to be obtained from the weirs of the Danube. On February 9th, 1915, a power station at Altwürttemberg, near Pleidelsheim on the Neckar, started operations,[6] with four vertical Francis turbines of 1,100 h.p. each. A steam peak-load power station typical of South Germany as an auxiliary to the water-power supply, is, for example, that of Münster on the Neckar.[7] The two

[1] *Südd. Ind. Blatt*, 1919, p. 2838.
[2] *Ibid.*, 1919, p. 1779.
[3] *Umschau*, 1919, p. 858.
[4] *Südd. Ind. Blatt*, 1920, pp. 1179 *et seq.*
[5] *Zeitsch. d. Ver. deutsch. Ing.*, 1918, pp. 838–839.
[6] *Südd. Ind. Blatt*, 1919, p. 2192.
[7] *Ibid.*, 1919, p. 2197; see Burkhardt, "Wasserspeicherung und ihre Bedeutung für die Wasserkrafte Württembergs," Stuttgart, 1920.

100,000-volt transmission lines from the Murg and the Pfalz Works are in communication through a connecting line 12 km. long.

According to the reports of the Wasserwirtschaftlichen Vereinigung für Mittel und Süddeutschland [1] (Water Power Association for Central and South Germany), development has not been neglected in other sections of Germany. In the river basins of the Leine, Oker and Bode (Harz), nine dams have been planned as a first development, and are partly destined to supply water to the Weser-Elbe Canal, but also to revive the previously highly developed water-power exploitation of the Upper Harz, which has unfortunately suffered through the decline of the mining industry. Five dams are also planned for the Werra district to hold 280,000,000 cu. m., three in the Fulda district to hold 280,000,000 cu. m., one in the Main district to hold 40,000,000 cu. m., and one or two in the valley of the Upper Saale to hold 500,000,000 to 600,000,000 cu. m.

The War demonstrated the value of natural water-power resources. We are not so much concerned with the exhaustion of the coal deposits, which need trouble us little to-day, as with the high price of coal and the fact that there exists a bitter necessity for Germany to utilise every ounce of its raw materials in order to reconstruct what the War has destroyed ; in this category we must include the utilisation of the available water powers Before the War there was a tendency to prefer power stations using fuel to those actuated by water power, on account of the higher capital and constructional costs of the latter, which might be five, six, or even ten times as large ; power stations utilising fuel are also more quickly erected, and can often supply current at a cheaper rate to communities which only require large supplies of current at intervals ; the necessity for lengthy negotiations regarding water power concessions also contributed to this result. It was generally considered before the War that where the annual period of consumption was less than 4,000 to 5,000 hours (one year = 8,760 hours), a kilowatt hour supplied by fuel was cheaper than when supplied by water power. A regular demand for current is the first essential in order to ensure a uniform load on the machinery, and peak loads are very detrimental. The addition of small electro-chemical plants in order to equalise the load, has often been proposed.[2] We are particularly interested here in the fact that, apart from carbide furnaces, the oxidation of atmospheric nitrogen has been proposed for this purpose. The railway power station at Muldenstein, near Bitterfeld, Province of Saxony, was planned to include an atmospheric nitric acid plant.

[1] *Südd. Ind. Blatt*, 1920, pp. 1232–1233.
[2] *Ibid.*, 1920, p. 857.

For such water-power stations, in particular, the addition of electro-chemical works is desirable, as they constitute the most uniform possible outlet for power. It is therefore in no way an accident that the first large German water-power station at Rheinfelden, constructed in 1898 for 18,000 h.p., was especially built for supplying an electro-chemical industry. Quite modern power works have been erected at Augst-Whylen on the Upper Rhine, on the Murg, near Forbach, and in the Möhne Valley in Westphalia.[1] When transmitting power to great distances, direct current may become more economical than alternating or three-phase current.[2] In a critical article,[3] W. Halbfass discusses the many advantages which also accrue to agriculture through the systematic damming of valleys.

With the increasing exploitation of water power, the question of steam boilers directly heated by electricity has become of increasing importance. According to the A.E.G.,[4] who construct patent boilers for this purpose, 10,000 kw. produce 30 tons of steam at 6 to 8 atmospheres in twenty-four hours during continuous working. In Scandinavia, where electric power is cheap and coal is scarce, such electric steam boilers have been used for a long time.

An interesting article by W. Halbfass, of Jena, may be quoted at some length here, as it throws a new light on the relation between water power and nitrogen fixation. Halbfass recommends that water powers of 80 h.p. and upwards, at places where limestone quarries are available, should be utilised for the production of nitrogenous fertilisers by the process of Frank and Caro. When he also recommends that agriculturalists should instal and work small 100 h.p. plants, utilising twenty to twenty-five truck loads of limestone annually to produce 1,600 to 2,000 cwt. of synthetic nitrate, requiring the services of one man only, it is evident that he does not in the least realise the difficulties attaching to nitrogen fixation.[5] The suggestion that such installations would serve to render agriculture independent of the heavy chemical industry and of railway transport is written from a purely theoretical standpoint. His statements that the use of water power would enable such nitrogenous fertilisers to be sold at two-thirds of the usual price, and that 1,000,000 h.p. so utilised for the fixation of nitrogen would increase the harvest by 2,000,000 to 2,500,000 tons, does not correspond to the facts in this general form, as will be seen from the following approximate

[1] *Umschau*, 1920, pp. 341 *et seq.*
[2] *Ibid.*, 1920, p. 432.
[3] *Die Technik i. d. Landwirtsch*, 1919, pp. 125 *et seq.*
[4] *Umschau*, 1919, p. 75.
[5] "Deutschland, nutze deine Wasserkräfte," Leipzig, 1919.

calculations which he gives :—"To fix 1 kg. of nitrogen as calcium cyanamide requires 17 k.w.h.—that is, 23 h.p. years produce 43·8 tons of cyanamide, equal to 8·36 tons of nitrogen, or 1,000,000 h.p. correspond to 1·9 million tons of cyanamide, that is, 380,000 tons of nitrogen. One ton of nitrogen increases the harvest by 20 tons in the case of wheat and by 100 tons in the case of potatoes. Therefore 380,000 tons of nitrogen would increase the harvest by 7·6 million tons of wheat or 38,000,000 tons of potatoes."

Among the natural sources of power which could replace coal we must include power from the sun, waves, and wind. The utilisation of the tides has been repeatedly attempted in practice without any definite success. The experiments of Hermann Plauson, of Hamburg, have attracted some attention (H. Plauson, "Gewinnung und Verwertung der Atmosphärischen Elektrizität, Beitrag zur Kenntnis ihrer Sammlung, Umwandlung und Verwendung," Hamburg, 1920, Boysen and Maasch). Plauson utilises the differences of potential in the atmosphere which, near the surface and on level ground, may attain about 100 volts per m. in summer and 300 volts per m. in winter; he proposes to obtain 1,000 kw. from a collecting area of 6 sq. km. by balloon antennæ. He refers to the possible application of these experiments to the atmospheric nitrogen industry and the manufacture of carbide. In principle, the experiments are not new.[1] It is to be hoped that they may be crowned with greater success than those of previous experimenters. Böning points out, in the *Südd. Industrieblatt*, 1919, 2203/4, the very small amount of electricity per cu. m. of air, which amounts to 0·3 to 1·5 electrostatic units only.

The German nitrogen fixation industry, the various developments of which have just been considered, received its main impulse through the outbreak of the Great War in 1914. It was in no way created by that War, for all the processes which were concerned were already practised before 1914, though on a very much smaller scale. Whereas the other branches of the nitrogen fixation industry have developed internationally, the Haber process has until recently been restricted to Germany only, as it is completely suited to the highly developed German chemical industry.

The question of power is all-important for the cyanamide industry and that of fuel for the Haber-Bosch process. Being essentially dependent on coal, the coke ovens and gasworks have been more immediately affected by the consequences of the Treaty of Versailles than other branches of the nitrogen industry. In accordance with this Treaty, 2,039 tons of ammonium sulphate were delivered to the Entente States up to the end of May, 1920. Under the pre-

[1] See, *e.g.*, C. Rudolph, German Patent 98,180 (1898).

sent economic conditions the development of peat and of water-power, and the search for new sources of energy, seems to be of particular interest. Under the circumstances the introduction of technically satisfactory methods of utilising the sulphur in coal, and of preserving the nitrogen in liquid farmyard manure, also seem particularly important.

According to the report of the Zentralgenossenschaft zum Bezuge Landwirtschaftlicher Bedarfsartikel in Halle-a.-S. (Central Association for the Supply of Agricultural Requirements of Halle-a.-S.), it was not possible, until the autumn of 1920, to obtain sufficient supplies of nitrogenous fertilisers, more particularly of cyanamide, ammonium sulpho-nitrate, etc. By enabling the material to be supplied in sufficient quantities, after the crisis produced by the revolution, the German nitrogen industry has achieved a considerable success. When discussing the nitrogen monopoly and the nitrogen syndicate, we described the more recent difficulties of distribution and the future possibilities. It is necessary to bear these latter in mind; they depend more particularly on the improvement of the economics of the process, on lowering the price of the product in the national interest, supplying individual industries with new sources of energy, and the elaboration of new methods, such as the gypsum process and the production of urea, and, finally, on the introduction, supported by propaganda, of new fertilisers of greater efficiency.

At suitable sale prices no excessive production of nitrogenous compounds is to be feared in Germany in the near future. On the contrary, the sales prospects are, in general, good. In the present situation, which is influenced by so many factors, it is impossible to say whether the large export of nitrogenous fertilisers, which was spoken of so hopefully during the War, can be realised in the near future. The formation of a trust comprising the whole of the Chile nitrate industry still lies in the distant future, especially as the sale of nitrate is prejudiced by a mistaken policy of sales and prices of the united producing interests. (Report for 1919–20 of H. B. Sloman & Co., Nitrate Works, Hamburg.) There is, for the present, no possibility of competition between natural Chile nitrate and the German synthetic product in the German home market, on account of the considerable effect of freight charges, exchange fluctuations, etc. Should competition arise it would, under normal circumstances, probably end in a victory for the synthetic product. It must, however, be remembered that the prices paid in 1914 for by-product ammonium sulphate and for Chile nitrate were artificially fixed by sale conventions, so that they might be considerably lowered under stress of competition.

Supplement, 1921–4.

The following articles have appeared in the interval :—

Chem. Ztg., **1921**, 324 ; **1922**, 100, 146, 180, 215, 360, 404, 660, 712, 823, 1098, 1120 ; **1923**, 68, 107, 164, 399, 447, 468, 492, 500, 508, 580, 612, 688, 716, 732, 739, 792.

Metallbörse, **1923**, 1609 ; **1924**, 536.

The disturbances in the exchanges caused extraordinary rises in the prices of fertilisers, which continued to be officially controlled ; they attained a maximum of 129,400 marks per cent. per kilogram of nitrogen in dry ammonium sulphate, 114,100 marks per 100 kg. in calcium cyanamide, and 154,200 marks per 100 kg. in sodium nitrate on July 22nd, 1923. These figures were then converted to a rye basis on August 15th, 1923, and to a gold mark basis on September 24th, 1923. At present ground neutral ammonium sulphate costs 1·17 mark per kg. per cent. of nitrogen, artificial Chile saltpetre 1·35 mark, and cyanamide 1·10 mark in the same units. The Nitrogen Syndicate supplies :—

Ammonium sulphate containing 20·6 per cent. nitrogen as NH_3.

Ammonium chloride containing 20 per cent. N. as NH_3.

Leuna saltpetre (ammonium sulpho-nitrate) containing 8 per cent. N. as $NaNO_3$ and 19 per cent. N. as NH_3.

Potassium ammonium nitrate containing 8 per cent. N. as nitrate, 8 per cent. N. as NH_3 and 25 per cent. of potash.

Sodium nitrate containing 16 per cent. N.

Calcium cyanamide containing 20 per cent. N.

The coal production, and the consequent production of by-product ammonia, dropped considerably, being 173,000,000 tons in 1913, 130·3 million tons in 1922, 62·2 million tons in 1923 (exclusive of Alsace-Lorraine). The coal imports increased correspondingly. The production of lignite was 1913, 87·2 million tons ; 1922, 137·07 million tons ; and 1923, 188·248 million tons. The production of coke in the present area, excluding the Saar, was in 1913, 31·668 million tons ; 1922, 29·11 million tons ; 1923, 12·7 million tons.

The production of calcium cyanamide was 1913, 48,000 tons ; 1921, 250,000 tons ; 1923, 238,000 tons. The production of ammonium sulphate is now about 1,000,000 tons in consequence of the large production of the Leuna Factory and the Badische Anilin und Sodafabrik. The difficult credit conditions and lack of money at the turn of the year 1923–24 caused grave difficulties in the home sales of nitrogenous fertilisers, and considerable financial exertions were necessary in order to overcome these difficulties.

The number of existing nitrogen works has diminished, as the A.G. für Stickstoffdünger at Knapsack and Cologne, and also the Mitteldeutsche Stickstoffwerke Gross Kayna have closed down. Oppau suffered under the conditions due to the military occupation; Zschornewitz has not been rebuilt since the explosion, and Chorzow, in Upper Silesia, now belongs to Poland.

As the Waldshut Works of the Lonza A.G. were not working continuously, and the production of the greater number of the coke ovens in Western Germany and Upper Silesia was of hardly any account, the only localities of really large scale production, apart from numerous gasworks, were Trostberg, in Upper Bavaria, and Piesteritz, both of which produce calcium cyanamide, and the Leuna Works of the B.A.S.F., near Merseburg (Haber ammonia, which is converted into sulphate by means of gypsum or sold as a mixed nitrate fertiliser).

The Kontinentale Stickstoffwerke A.G. ("Casag"), which was founded in Munich in 1922 (*Chem. Ztg.*, **1922**, 232, 332, 604; *Chem. Ind.*, **1923**, 419; *Metallbörse*, **1923**, 616), are erecting a works on the Pauling arc system at Golbing, near Salzburg, to supply German Austria.

Arrangements between the B.A.S.F. and France concerning the grant of Haber licences have been concluded (*Chem. Ztg.*, **1921**, 468; **1922**, 440; **1923**, 172, 191, 256; *Chem. Ind.*, **1923**, 131, 155; *Metallbörse*, **1923**, 111, 208, 310, 425).

CHAPTER IV

The Norwegian Nitrogen Industry

THE history of the Norwegian nitrogen industry commences on May 2nd, 1905, at which date the Notodden Works in Telemarken commenced continuous manufacture, thus proving the economic applicability of the Birkeland-Eyde process on the large scale. Since that date Norway has been the foremost country of the atmospheric nitric acid industry.

Christian Birkeland, who died in 1917, was Professor of Physics at the University of Christiania. In 1903, in the course of other investigations, he noted that the alternate current arc was distorted to form a disc in the magnetic field.[1] The results of Birkeland's investigations agree with those of earlier physicists, but he made the original observation that high tension arcs in air, which were distorted in this manner, caused an extraordinarily energetic combustion of atmospheric nitrogen. This fact was utilised by Birkeland and his collaborator, the engineer, Samuel Eyde, to elaborate a new method of obtaining nitric acid from the air. Eyde undertook the administration of the company formed for this purpose; this was afterwards converted into the Norsk Hydroelektrisk Kvaelstof A.S., of which Eyde was chosen as the General Director. On his fiftieth birthday, on October 29th, 1916, Eyde presented 50,000 kr. to his birthplace, Arendal, and 20,000 kr. to the Norsk Ingeniör-forening and the Polyteknisk Forening in Christiania; the Norsk Hydro, as it is ordinarily called, established a Samuel Eyde Fund in his honour, amounting to 100,000 kr., for the promotion of physical and chemical research.

The first experimental works, at Ankerlökken, near Christiania, were replaced by a rather larger plant at Vasmoen, near Arendal, which was followed by the works at Notodden. The watercourses of the Hitterdal unite to form a lake near the township of Notodden, which lake is connected through a series of navigable canals with Skien-Fjord, and thus with the open sea. Skien, the port of shipment for Norwegian saltpetre, lies on the south coast of Norway, about 100 km. from Christiania as the crow flies. Close to Notodden the Tin-Elf forms the Tinfos, which provides 20,000 h.p., and 4 km.

[1] O. N. Witt, *Chem. Ind.*, 1905, pp. 699 *et seq.*

above this is the Svälgfos, providing 30,000 h.p. At that time electrical energy cost 12 marks (12*s*.) per horse-power year, that is, about 0·19 pfg. per kilowatt hour. Towards the end of 1906 the Norsk Hydro was already in touch with the B.A.S.F., and since 1905 the latter company has been interested in large-scale experiments according to the Schönherr process. By arrangement between the two companies the new works to be built on the Rjukan was to be provided with furnaces built according to both systems.

In the autumn of 1907 the B.A.S.F. established their experimental plant at Fiskaa, near Kristiansand, which was supplied with three-phase current from the power station, 26 km. distant, of Kringsjaa in the Saeterstal. The development of the Haber process and other causes induced the I.G., representing the B.A.S.F., to dissolve the Norwegian arrangements. The liquidation was almost complete in 1912. The Fiskaa Works, which had been founded in 1907 as a special share company with 200,000 kr. capital, were sold to a Norwegian company, which intended to use it for other manufacturing purposes.

Soon after the works at Notodden had proved successful during continuous manufacture, the Norsk Hydro commenced to develop the Rjukanfos. The Rjukan is the most powerful waterfall in Norway. It is situated in the interior of Telemarken. It has a natural fall of 260 m. and a regulated fall of 560 m., down which the Maan-Elf passes in four enormous leaps on its way from the Mjösvand Lake. When the water is utilised to the amount of 40 cu. m. per second, 250,000 to 300,000 electrical horse power can be developed from the fall. The development was carried out in two stages, each of 280 m. fall. The first portion of the Rjukan development was put into operation at the end of May, 1912, comprised ten turbines and developed 107,000 kw. The second portion was added during the War (Rjukan II., 1916–17), and to-day the Rjukan Works dispose of about 290,000 h.p. They are connected with Notodden and Skien by a normal gauge railway 46 km. long, and a ferry across the Tin Lake which is 40 km. long. The Rjukanfos Company and the Norsk Transport A.S. are affiliated to the Norsk Hydroelektrisk Kvaelstof-Aktieselskab (Notodden), with headquarters at Christiania. The liquidation of the German interests led to the absorption of this important industry by Franco-Norwegian financial groups in the form of the Société Norvegienne de L'Azote et de Forces Hydro-électriques. In this way, during the War, more than 350,000 h.p. in Norway was at the disposal of the Entente.[1] We will return to these relations later.

[1] C. Matignon, *Revue génér. des Sciences pures et appliques*, **28**, 6 and 50.

The great development of the atmospheric nitrogen industry led to a considerable increase in the employment of Norwegian water power. The total power available is estimated at 7·5 to 8 million h.p., and that which could easily be harnessed at least 5,000,000 kw. (6·7 million h.p.). The cost of development varies very greatly, and is ordinarily estimated at 250 to 400 kr. per kilowatt, which at the pre-war rate of exchange is 280 to 448 marks. The annual charges, including amortisation, may be estimated at 10 to 15 per cent. of the original constructional cost, so that in 1918 at large power stations the kilowatt year cost about 45 to 60 kr., that is, 50·40 to 67·20 marks at the pre-war rate of exchange—*i.e.*, about 0·58 to 0·77 pfg. per kilowatt hour. These costs are usually lower in the western and northern part of the country than in the east and south, as in the former the waterfalls are more favourably situated. The above cost is for power deliveries of not less than 5,000 to 10,000 kw. at 5,000 to 15,000 volts at the ports. If the works are in the direct neighbourhood of the power station, the cost per kilowatt hour is lower; 863,000 h.p. were developed between 1905 and 1915, and in 1917 alone the additional water-power development exceeded 250,000 h.p. In 1913 705,000 h.p. had been developed, of which 400,000 h.p. were used in electro-chemical and metallurgical industries. The Hardanger district alone could supply 900,000 h.p. The following table gives a summary of some of the more important works which have been carried out or planned during the last few years:—[1]

Company and Place.	Power.	Manufacture.
A.S. Perclorat, Odda. (Concession applied for.)	23,000 h.p., Tysse waterfall. 100,000 h.p. in all, of which 20,000 from the Blaa Falls in the first stage of development.	Perchlorate, etc. Carbide.
Öyro, Ryfylken district, (Purchased.)	70,000 h.p., Saude Falls. Maarforsen Falls.	Carbide. Electro-chemical works.
Konsortium in Skien.	Jostedals and Lardals Falls in Sognefjord, 200,000 h.p.	Nitrate, aluminium, carbide.
A.S. Bremanger Kraft-Selscab, of Bergen.	Soend Fjord, near Florö, 30,000 h.p.	Carbide ferro-silicon; some cyanamide.
A.S. Bjolvefossen, Hardanger Fjord.	Bjolvefos, 20,000 h.p., and a further 44,000 h.p.	Carbide and cyanamide.
Titan Company (projected)	Thorsaa River in Iceland, Gaudefaldene waterfalls, 100,000 h.p.	Norway saltpetre, carbide and other products.

[1] See K. Arndt, *Chem. Ind.*, 1919, No. 22–23.

An electric supply commission has been established in Norway in order to ensure a co-ordinated electrification of the country.[1] In 1915 the seven carbide works in Norway disposed of 100,000 h.p.

In 1915 the Norwegian chemical industry had a total share capital of about 150,000,000 kr., which was mainly in foreign hands. In 1916 35,000,000 kr. of fresh capital were added, and in 1917 40,000,000 kr., these additions being almost exclusively Norwegian capital. The development of German-Norwegian joint interests is controlled by the Deutsch-Norwegische Wirtschaftsverband, which was founded in Berlin in 1919 on the premises of the Norgesalpeter Verkaufs G.m.b.H.[2]

The Norsk Hydroelektrisk Kvaelstof A.S. paid dividends of 8 per cent. in 1914–15; 10 per cent. in 1915–16; 10 per cent. in 1916–17; and 12 per cent. in 1917–18. A new air nitrate plant at Ranen, in Nordland, was projected, and a package factory was to be built in 1917 on the Island of Heröen, near Porsgrund. The effect of the War was rapidly to increase the production of nitric acid and ammonium nitrate. The importation of ammoniacal liquor from England was hampered after the establishment of the German blockade. The Norwegian works at Odda and Notodden delivered synthetic ammonia in small amounts which were quite insufficient, so that the production of ammonium nitrate at Saaheim-Rjukan fell to less than half after the middle of February, 1917. After the end of 1918 Norway saltpetre only was produced. Since the manufacture of ammonium nitrate at Notodden has ceased, this product is only produced in very small quantities. The Odda Works manufacture calcium cyanamide and ammonia. The weekly output capacity of the Norsk Hydro Works is now 30,000 barrels of Norway saltpetre—that is, about 156,000 tons per year, or 100,000 to 120,000 tons of 96 per cent. nitric acid. The works utilise about 350,000 h.p. The Rjukan I. Works, which utilise 140,000 h.p., and have a normal daily output of 200 tons of Norway nitrate, are the largest air nitrate works in the world. In order to supply the necessary sodium carbonate, alkali works have been built at Rjukan with a present yearly output of about 1,000 tons. A large research laboratory in Christiania serves for the improvement of the processes. The Rjukanfos Company distributed a dividend of 20 per cent. in 1917–18 as a branch of the Norsk Hydro, and the Norsk Transport A.S. distributed a 15 per cent. dividend. The total share capital of the company amounted to 191,609,192 kr. in 1919, of which 86,214,223 kr. repre-

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 391.
[2] *Chem. Ztg.*, 1919, p. 492.

sented the capital of the six affiliated companies and various other securities.

The capital of the Norsk Hydro in 1915 was only 62·54 million kr., the Svaelgfos Waterfall at Notodden being valued at 3·56 million kr., and the Notodden Works at 16·87 million kr. This capital was not nearly sufficient for the enlargement of the enterprise and for the formation of the affiliated companies, as the acquisition of an interest in the Rjukan Works alone required 66·4 million kr. As the issue of debentures is not permitted by Norwegian law, the company would have had to increase their share capital to an enormous extent in order to meet all these requirements. The difficulty was evaded by the formation of the French firm "Société Norvégienne de l'Azote et de Forces hydro-électriques" in Notodden, which issued the necessary debentures in France and at the same time developed further the already intimate association with French high finance. This loan was based on the liquid assets of the Norsk Hydro as a security, and the interest had to be paid by the Norsk Hydro through the Société de l'Azote. In the balance sheet of the Norwegian Company the formation of the French Company appears at a figure of about 66,500,000 kr. The Société Norvégienne de l'Azote has also recently been active in the Pyrenees.

The Notodden Works, with the power stations of Tinfos and Svaelgfos, utilise about 50,000 h.p., and the Saaheim-Rjukan Works are supplied with 140,000 h.p. by the Rjukan I. power station and with 150,000 to 160,000 h.p. from the Rjukan II. station, so that the Norsk Hydro utilises a total of 340,000 to 350,000 h.p.

Originally calcium nitrate (Norway saltpetre) only was manufactured, containing about 13 per cent. of nitrogen. At a later date 98 per cent. nitric acid was successfully produced on a large technical scale; after adding 10 per cent. of sulphuric acid, this was despatched in iron drums. During the War the production of ammonium nitrate from English and later from Norwegian ammonia, became more important; the Norwegian ammonia was obtained from nitro-lime. Sodium nitrate and sodium nitrite are obtained as by-products of the alkaline absorption of the nitrous gases.[1] In 1913 Norsk Hydro produced 1 kg. of HNO_3 in the dilute condition, at a production cost of about 0·20 kr. compared with 0·45 to 0·60 kr. by the old method from Chile nitrate. When fully occupied, Notodden Works employ about 2,000 people. The company has built large colonies for the workpeople. The process has always worked smoothly, but there were several strikes during the War. The transport arrangements

[1] During the War the Norsk Hydro erected their own alkali works with a daily output of 27 tons (*Chem. and Met. Eng.*, 1920, p. 1082).

have latterly been increased on a large scale by the erection of large storehouses and quays at Menstad, opposite to Borgestad. Very valuable technical details have been communicated by E. Kilburn-Scott.[1] The Notodden Works comprise 32 Birkeland-Eyde furnaces of 600 to 1,000 kw. each, and at Saaheim there are eight Birkeland-Eyde furnaces of 3,500 kw. each, and also a few Schönherr-Hessberger furnaces, each of 1,000 kw. It is worth noting that the Norsk Hydro, as the representative of French groups, opened a branch at Stockholm in 1920 [2] with 50,000 kr. capital, to represent the Alsatian Potash Works in Sweden. The direct importation and sale in the United States of ammonium nitrate, Norway saltpetre, and sodium nitrite produced by the Norsk Hydro, is carried out by the newly founded Norwegian Nitrogen Products Company of New York.[3]

During 1918 the Norsk Hydro and the Norsk A.S. for elektrokemisk Industri of Christiania, founded the A.S. Labrador with 2,000,000 kr. capital, for the production of alumina and calcium nitrate by treatment of Norwegian labradorite with nitric acid. The Norsk A.S. for elektrokemisk Industri formerly belonged to the Brandenburgischen Elektrizitätswerke, and is less concerned with the chemistry of nitrogen products than with the production of carbide, aluminium, carborundum, etc. In 1918 it had a capital of 28·8 million kr., and distributed dividends of 5 per cent. in 1916, and 7 per cent. in 1917. The company is the owner of works at Kragerö and Eydehavn, near Arendal. It is mainly of interest to us here on account of its acquisition of the majority of the shares of the Fiskaa Works at Kristianssand, which is well known to have been founded by the B.A.S.F.

The Norsk Nitrid A.S. at Eydehavn, near Arendal, which was originally intended to produce aluminium nitride, produces aluminium chiefly, as the difficulties of the Serpek process were found to be too great. Under the name of Société Norvégienne des Nitrures, the company is closely connected with the French Société Générale des Nitrures at Paris, to which it is affiliated. Of the total 25,000 h.p. which are available, 10,000 h.p. have at present been developed from the Boïlefos.[4] The capital of the Norwegian Company is 13,000,000 fr. The business report for 1914–15 does not report very favourably on the Serpek process; the plant was ready at the end of 1913.

The Odda Works at Hardanger Fjord were founded in 1908, and are one of the first of the largest existing carbide works; they are

[1] *J. Soc. Chem. Ind.*, 34, 113–126.
[2] *Zeitsch. f. angew. Chem.*, 1920, ii., 82.
[3] *Chem. Ztg.*, 1920, p. 648.
[4] *Ibid.*, 1913, pp. 303, 646.

the property of the North-Western Cyanamide Co., Ltd., of London, and work on the Frank-Caro system ; in 1915 they utilised a total of 50,000 h.p. ; the output capacity was 24,000 tons of cyanamide in 1912, and 52,000 tons in 1913. This output was at first greatly reduced at the outbreak of War, but was then increased to 90,000 tons of carbide, corresponding to 112,500 tons of cyanamide, containing 20 per cent. of nitrogen. With the assistance of the Alby United Carbide Factories, Ltd., and the North-Western Cyanamide Co., Ltd., the Nitrogen Products and Carbide Co., Ltd., of London, was formed in 1913, together with the affiliated company, Nitrogen Fertilisers Co., Ltd., with a total share capital of 36,000,000 kr. The Alby Works of the Alby Carbidfabriks Aktiebolag have been working continuously since the summer of 1912 and produced 15,000 tons of cyanamide in 1912. The formal amalgamation of the Alby United Carbide Factories, Ltd., and the Nitrogen Products and Carbide Co., Ltd , took place in 1919. The Alby Works were later taken over by Swedish interests (see next chapter).

The Odda Works in Norway are supplied with electric power (65,000 h.p.) from Tyssedal ; the waterfalls at this locality represent a total of 125,000 h.p., of which about 83,000 h.p. have now been developed. During the first years of the War Odda delivered considerable quantities of nitro-lime to the English Dagenham Works, which were to have produced ammonia from this material, and to have further oxidised this to nitric acid, using platinum contacts. The Dagenham Works had great difficulty in obtaining their supplies, as Norwegian imports were seriously affected by the German blockade. They finally used gas liquor as their raw material. During the War Odda also supplied Notodden with ammonia for the production of ammonium nitrate. It includes a special granulation plant for the production of nitro-lime for fertilising purposes. The Belgian Works at Vilvorde were already supplied in 1913 with cyanamide from the Norwegian Works, which served for the production of ammonium sulphate and ammonium nitrate (see Chapter X). The Nitrogen Products and Carbide Company hold a number of further concessions in Norway for the development of waterfalls at Aura, Mardöl in Romsdalen, and other places. The Meraker Carbide and Smelting Works produce carbide and ferro-alloys only.

The Purchasing Union of the Agricultural Associations in Norway started the erection of their own works for nitrogenous fertilisers in 1915, the A.S. Bjölvefossen at Indre Aalvik, Hardanger, which started operations in 1918. It disposes of 36,000 to 43,000 h.p. from the Bjölva Falls, and the company also owns limestone deposits containing 10,000,000 tons of limestone. The annual output capacity

is about 36,000 tons of cyanamide produced in four Carlson furnaces, and, as a by-product, 6,000 tons of ammonium sulphate. In 1919–20 the works stopped producing carbide, as did the Odda Works, for reasons which will be explained later.

The Norsk Superfosfatfabriker manufacture lime fertilisers and other products. The A.S. Bremanger Kraftselskab of Bergen, first developed 21,000 h.p. from their water powers at Bremanger ; they intend to produce 30,000 tons per annum of carbide, of which one-third is to be converted into cyanamide. In 1915 the capital of this company was 5·4 million kr. ; the works are at Soend Fjord, near Florö, and so far they have mainly produced ferro-silicon. The A.S. De Elektrokemiske fabriker Sodium in Trondhjem manufacture alkalies and chlorine. The A.S. Kvina Carbid og Smelteverk, which was founded in 1915 with a capital of 0·76 million, erected a carbide works at Fedefjord, near Flekkefjord. They are supplied with 5,000 h.p. by the A.S. Trälandsfos in Kvinesdal, which also supplies the neighbouring A.S. Carbidindustri with 15,000 h.p. The latter company purchased for 1,000,000 kr. the Organokemisk Industri A.S. at Frederikstad, which was founded in 1916. In this works carbide is converted into alcohol, acetic acid, etc., by a process due to the engineer Sverre Utheim of Frederikstad. Hugo Laurell, engineer, erected a carbide works for the A.S. Norsk Elektron at Bergen with a capacity of 20,500 tons per annum to utilise his process. Power is supplied by the Blaa Falls. During the War the Usines Electrochimiques de Hafslund, near Sarpsborg, produced ferro-silicon. In 1919 these works reconstructed their three furnaces and returned to the production of carbide. They and the Norsk Elektro-kemisk A.S. were placed on the British black list on account of War deliveries to Germany. The Nitro-glycerin Company of Christiania produces a special ammonium nitrate safety explosive known as Extra-Nobelit, which does not lose its explosive powers, even though placed in water for hours. Schjelderup of Bergen, Helgeby of Trondhjem, and Bull of Bergen have worked out a new process in order to increase the yield of gas and ammonia on distilling coal.[1]

The area of the Norwegian moors is estimated at 12,000 sq. km. (1,200,000 hectares). Half of this area seems to be unsuitable for exploitation ; of the other half, 3,000 sq. km. seem best suited for reclamation, 2,000 sq. km. for the production of peat-fuel, and 1,000 sq. km. for the production of peat litter. In order to avoid monopolisation by foreign interests, a law was passed on July 25th, 1913, which stipulated that the acquisition of moorland areas of more than 35 hectares should in future be subject to a special royal

[1] *Chem. Ztg.*, 1919, p. 271.

grant, unless the purchasers were the Norwegian Government, Norwegian communities, or Norwegian citizens.[1]

In 1914–15 a project was formed for the establishment of coke ovens in a Norwegian coast town to deal with coal from Spitzbergen.

In 1918 100 kg. of Norway nitrate or so-called "Norwegian Chile nitrate" cost 24 kr., 100 kg. of nitro-lime fertiliser cost 21 kr., and 100 kg. of 18 per cent. nitro-lime as a weed-killer 22 kr., including sacks, f.o.b. or f.o.r., delivered by the North-Western Cyanamide Company of Odda; 100 kg. of Chile nitrate cost 23 kr. in 1919. The sale of nitrogenous fertilisers is not controlled by the State, but superphosphate and potash salts were rationed in 1919. The State pays considerable subsidies in order to reduce the price of fertilisers, and in 1918–19 these amounted to 13·6 million kr. for air nitrate, 1·0 million kr. for cyanamide, and 3·6 million kr. for superphosphate.

According to a report of the Norwegian Department of Agriculture, the following quantities of fertilisers were available in 1919: 80,000 tons of calcium nitrate, 2,500 tons of finely ground nitro-lime, 2,500 tons of granulated nitro-lime (cyanamide), and 43,000 tons of superphosphate. The actual deliveries, however, amounted only to 50,000 tons of synthetic calcium nitrate and Norwegian (synthetic) sodium nitrate. The exports of calcium nitrate in 1919 were 10,000 tons to Denmark and 20,000 tons to Sweden. Before the War the domestic consumption of Norway amounted to only 6,000 to 7,000 tons of nitrogenous fertilisers annually. The following summary of Norwegian conditions before the War is abstracted from an article by J. Sebelien:—[2]

Year.	Production of Calcium Nitrate in tons	Domestic Consumption of Calcium Nitrate in tons	Imports of Chile Nitrate for Industrial Purposes in tons
1905	127	5·4	707
1908	15,000	470	1,615
1910	18,569	1,860	258
1913	73,214	5,500	103

The exports of calcium nitrate were 51,701 tons in 1912 and 70,171 tons in 1913, valued at more than 11,000,000 kr. The exports of sodium nitrite, sodium nitrate, and ammonium nitrate were 13,480 tons in 1912 and 17,028 tons in 1913; 50,000 tons of calcium carbide were exported in 1910.

[1] *Chem. Ztg.*, 1914, pp. 110, 111.
[2] *Ibid.*, 1914, p. 1109.

The imports of Chile nitrate, which were 1,337 tons in 1913 and 783 tons in 1914, ceased almost completely during the War, being 44 kg. in 1917 and 6 kg. in 1918. The production in tons per month in Norway in 1918 and 1919 was as follows :—[1]

	August, 1918.	August, 1919.	January to August inclusive, 1918.	January to August inclusive, 1919.
Ammonium nitrate .	4,327·2	562·4	32,008·8	1,038·6
Sodium nitrate .	29·9	1,844·3	2,264·5	3,498·6
Calcium nitrate .	2,953·7	3,807·9	40,199·0	34,806·4
Nitric acid . .	97·8	163·7	468·4	698·5
Ammonium sulphate	—	70·3	—	199·2
Calcium cyanamide.	—	—	0·5	7,981·7
Calcium carbide .	4,342·5	525·2	29,423·6	15,571·0
Oxalic acid . .	54·3	69·1	143·9	189·9

The table clearly shows the decline in the output of ammonium nitrate, a war material, and the renewed growth of the output of calcium cyanamide. The total exports of chemicals from Norway in 1917, 1918 and 1919 were as follows, in tons :—

	1917.	1918.	1919.	First Six Months of 1913 for comparison (Certain Items only).
Nitric acid . .	1,621·2	836·7	1,432·8	—
Oxalic acid . .	334·1	206·0	293·4	—
Ammonium sulphate	50·0	—	232·5	—
Ammonium nitrate.	63,578·1	49,587·6	5,163·1	4,246·0
Sodium nitrate .	22,711·2	2,636·6	13,036·4	—
Sodium nitrite .	3,536·1	2,097·8	1,893·0	32,050·0
Calcium nitrate .	35,932·4	53,625·3	63,880·2	2,764·0
Calcium cyanamide.	2,312·9	10·5	9,929·9	11,000·0
Calcium carbide .	46,066·6	41,771·9	25,599·3	—
Iodine . . .	1·2	5·4	3·0	—

In 1915 the works of the Norsk Hydro at Notodden and Rjukan produced 38,000 tons of calcium nitrate (75,000 tons in 1914) and 26,000 tons of ammonium nitrate (12,000 tons in 1914). In 1916 the production of calcium nitrate was 86,000 tons, of which 64,000 tons were exported (70,171 tons in 1913), and 40,000 tons were used

[1] *Chem. Ind.*, 1920, p. 158 ; *Zeitsch. f. angew. Chem.*, 1920, ii., 113.

within the country. The present output capacity of the Norsk Hydro Works is 100,000 to 120,000 tons of concentrated nitric acid of 96 to 99 per cent., or at least 156,000 tons of calcium nitrate, equivalent to 30,000 barrels per week of 100 kg. each. In 1916 4,000 tons of free nitric acid were produced. The output of Odda and Notodden now consists almost exclusively of calcium carbide, ammonium nitrate and sodium nitrate, which are sold through a central selling agency of the Norsk Hydro.

When all the plants at present under construction are finished (such as Aura, A.S. Bremanger, and so forth), and if the whole available power is used for manufacture, then the maximum attainable output of calcium cyanamide in Norway will amount to 700,000 to 800,000 tons per annum. The maximum output capacity in 1919–20 was about 250,000 tons, and the large discrepancy between the maximum output and actual production is shown by the small domestic consumption, which was only 5,000 tons in 1919, together with the small export figures, which were only 7,981·7 tons, from January to August inclusive, of 1919. The reasons for this discrepancy will be discussed later.

In 1916 Norway imported 16,000 tons of ammonia, mainly from England, and in addition 7,500 tons of ammonium sulphate. The total imports of ammonia and ammonium salts amounted to 18,164 tons in 1917 and 2,684 tons in 1918. The exports of Norwegian nitrogen products to Sweden and Denmark have greatly expanded, as is shown by the following table, which gives the amounts in tons :—

	Calcium Nitrate				Ammonium Nitrate.		
	1913.	1916	1917.	1918.	1916.	1917.	1918.
To Sweden .	139	1,130	1,425	15,605	110	317	560
,, Denmark .	4,500	—	—	21,170	—	—	—

Certain details of the commercial treaty of 1918 between Norway and the United States are of interest. According to this Treaty, Norway had to supply the United States with 112,000 tons of nitrates, 10,000 tons of calcium cyanamide, and 30,000 tons of calcium carbide per annum, whilst she was only allowed to supply to the Central European Powers 10,000 tons of calcium carbide and 8,000 tons of calcium nitrate. The disposal of Norway saltpetre in Germany is controlled by the Norgesalpeter-Verkaufsgesellschaft of Berlin.

Norwegian industry was greatly stimulated by the War, as is shown by the rapid increase in the development of water powers. In 1911 the developed water power amounted to 262,095 kw. from 1,139 electric installations. More particularly, very large funds were invested in Norwegian electrochemical enterprises during the War. At that time the profits in these branches of industry were very large. The position altered when the War ceased. The belligerent countries had assimilated large stocks of nitrogen products originally intended for the manufacture of munitions of war. There was thus a difficulty in disposing of such products in the case of undertakings as large as Norsk Hydro. There was the additional difficulty that at the commencement of 1919 prices dropped fairly rapidly. In spite of these facts, the general opinion in 1919 was still optimistic, and the prospects of nitrogen works were considered to be favourable, as it was supposed that after a restriction of output for two or perhaps three years, there would be a revival ; it was soon found that there was no ground for such optimism. Not only had 400 men to be dismissed from the large carbide works at Saude in November, 1919, but the manufacture of carbide at Odda and Bjölvesfossen had to be completely stopped. These two plants, however, are Norway's largest works for the production of calcium cyanamide. In consequence of increased prices, increased production costs and rapidly increasing wages, accompanied by reduction of working hours and decreased output, and other causes, the West Norwegian heavy chemical industry is now working under extremely difficult conditions which threaten ruin to certain firms.[1] Under these conditions, the prospects of exporting are very bad, as is clear from the fact that in 1919 Swiss carbide was offered in France at 700 fr. per ton, and Norwegian carbide at 1,000 kr. per ton f.o.b. Hardanger Port. It is very questionable whether, under such circumstances, a suitable moment has arrived for the vigorously demanded socialisation of the nitrogen fixation works of Norway.[2] In the middle of 1920 the price of Norwegian nitrate had risen to 48 kr. per 100 kg., as against 24 kr. in 1919, as the Government no longer assists the nitrate industry by special concessions, excepting that the freights are reduced to one-half.[3]

Supplement, 1921-24

The situation of the carbide works is so bad that most of them have been permanently closed down. Odda has been sold and is

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 10.
[2] *Ibid.*, 1919, ii., 434.
[3] *Metallbörse*, 1920, p. 1280.

now controlled by A.S. Tysse-Faldene (phosphazote from calcium cyanamide and phosphorite). The Electric Furnace Products Company at Saude has replaced carbide production by that of ferro-silicon since 1920 (*Chem. Ztg.*, **1922,** 52; *Chem. Ind.*, **1923,** 105, 156, 321, 591; *Metallbörse*, **1923,** 62).

Norsk Hydro hope to have overcome their serious crisis of 1921–2. A maximum production of 100,000 tons of concentrated nitric acid has now been attained by the Rjukan Works, which now dispose of a total of 270,000 h.p. after the further addition of 25,000 h.p. (*Chem. Ztg.*, **1923,** 95; **1924,** 36; *Chem. Ind.*, **1923,** 114, 270, 603; *Metallbörse*, **1923,** 237; **1924,** 211). A national arc nitric acid works may possibly be erected (*Chem. Ztg.*, **1922,** 404).

The output capacity for calcium cyanamide in 1918 was estimated at 178,000 tons; the production of calcium nitrate was 130,000 tons in 1921 and 156,000 tons in 1922. The exports in 1923 were 1,116 tons HNO_3; 1,792 tons NH_4NO_3; 32,401 tons $NaNO_3$; 1,674 tons $NaNO_2$; 157,558 tons calcium nitrate (Norge saltpetre); 3,829 tons calcium cyanamide and 21,004 tons calcium carbide. The Norsk Hydro Company estimate their exports for 1923 to be 100,000 tons Norge saltpetre (*Chem. Ztg.*, **1922,** 691, 712; *Chem. Ind.*, **1923,** 321, 383; **1924,** 20; *Metallbörse*, **1923,** 1078).

CHAPTER V

The Swedish Nitrogen Industry

SWEDISH industry has also developed very rapidly during recent years, as is shown by the following small table, which gives the value of the output of the electro-chemical works at pre-war prices :—

Year.	Number of Electro-Chemical Works.	Value of Output in Millions of kr.	Water-power in 1,000 kw.
1904	8	4·5	9
1908	10	7·5	13
1911	14	11·0	25
1913	22	20·0	60
1915	36	31·0	78
1917	75	55·0	126

The unfavourable transport conditions in Norrland at present hinder more rapid development of large electro-chemical industries. The centre-point of the electro-chemical industry now lies at Trollhättan, in the south of the country, where at the end of 1908 105,000 kw. were available ; this quantity will probably be increased to 270,000 kw. after the Vaner Lake has been controlled.

The development of Swedish water powers underwent a certain depression in 1919.[1] The national power stations provided the following quantities of energy :—

Power Station.	Maximum Load, kw.	Power Development in Million k.w.h.
Trollhättan	78,400	425
Porjus, three-phase current	9,400	74
Porjus, direct current	8,200	10
Alvkarleby and Motala	52,000	204
Other power stations	—	2
Increase or decrease per cent. compared with 1918	+4	—1·5

The first extension of the Motala station was to be ready in the autumn of 1921, but the works at Lilla Edet and Narspränget were

[1] *Südd. Ind. Blatt*, 1920, p. 1491.

being carried out more slowly. The electrification of the Swedish railways is proceeding. Among the private water-power stations Hemsjö provided 37,000,000 k.w.h., Gullspäng-Munkfors 27,000 h.p. (54,000,000 k.w.h.) and Stora Kopparbergs Bergslags A.B. 128·9 million k.w.h. The steel works at Domnarfvet utilise 6,500 h.p., and the extension of Forshuvudfersen was to be finished in the second half of 1921. There were Government projects involving an expenditure of 22,705,000 kr. in 1920 for the further development of water power at Harsprang in the Luleaelf basin, and so forth. New water-power resources are available on the Umeaelf and the Tyttbo Falls (Dalelf). In January, 1919, about thirty-five ironworks and other works in the Bergslagen district combined for the purpose of a joint administration and better utilisation of the available water power to form A.B. Bergslagens gemensamma Kraftförvaltning with a capital of 1·5 million kr. This company has also acquired the Kvangeds Falls in Norrland.

The oldest Swedish nitrogen fixation works is the Alby Carbidfabriks Aktiebolag, which manufactures calcium cyanamide in Alby by the Frank-Caro process, and which, together with Odda in Norway, is the property of the North-Western Cyanamide Company. This latter company is closely connected with the Alby United Carbide Factories, Ltd., of London, and the Nitrogen Products and Carbide Co., Ltd., London, which definitely combined in 1919. Before that date the majority of the shares of the Alby Company (capital of 2·5 million kr.) and of its power supply company, the Alby Vattenfalls A.B. (110,000 h.p.), were acquired from their former English owners for a cash payment by the Stockholms Superfosfatfabriks A.B., so that the nitrogen industry is now exclusively financed by Swedish capital. The interests of the Alby Company and of the Stockholm Superfosfatfabriks A.B., which owns a carbide works at Trollhättan, have been identical for a considerable period, and led to the formation by both firms of the Svenska Carbidkontoret at Göteborg, a joint-stock company founded in 1917 with a capital of 100,000 kr. for the sale of carbide.

By the absorption of the Alby A.B., the Nitroglycerin A.B., and other companies, the Stockholm Superfosfatfabriks A.B., which had a capital of 30,000,000 kr. in 1920, has become the largest chemical group in Sweden. In 1916 the A.B. Carlit (for perchlorate manufacture) and the A.B. Nitrogenium (for nitrogen fixation) were founded as affiliated companies, each with a share capital of 2,000,000 kr., for the exploitation of Carlson's inventions. The A.B. Nitrogenium erected four nitrogen fixation furnaces on Carlson's system at Bjölvefossen in Norway. The Stockholm Superfosfat-

fabriks A.B. now manufactures not only superphosphates, but also calcium cyanamide, ammonium sulphate, calcium carbide, ferro-silicon, potassium, sodium, and barium chlorate, potassium, sodium, and ammonium perchlorate, compressed ammonia, sodium nitrite, sodium sulphate (crystallised and calcined), water glass, calcium chloride, sulphuric, nitric, hydrofluoric, and perchloric acids, metallic sodium and explosives, such as carlsonit, detonators, etc. It owns its own wood-distillation plant with by-product recovery, also pyrites and wolframite mines. The company manufactures calcium cyanamide, not only in Trollhättan and in the Alby Works, which they own, but also in the new Ljunga Works. The Ljunga Works are named after the Ljungan River in Norrland, and only started to manufacture carbide in October, 1912, and calcium cyanamide at the commencement of 1913. On a smaller scale, they decompose calcium cyanamide to produce ammonium sulphate. They also own a small plant for the oxidation of ammonia to nitric acid and a small Birkeland-Eyde plant, which is, incidentally, the only one in Sweden. The calcium cyanamide is produced in Carlson furnaces.

The Alby plant has been working continuously since the summer of 1912. It is intended for an output of 12,000 to 15,000 tons of calcium cyanamide per annum. Alby and Trollhättan produced 4,307 tons of carbide in 1910 and 3,820 tons in 1911, and employed 134 workpeople in the latter year. As Alby is close to Sundsvall at the mouth of the Ljungan River, on the coast of the Gulf of Bothnia, it was to be anticipated that it would combine with the Ljungan Works of the Stockholm Superfosfatfabriks A.B. In 1914 8,000 tons of carbide and 9,500 tons of calcium cyanamide were produced at Alby Works. Its carbide furnaces, known as "Alby furnaces," have led the way in many respects. The Alby Water Power Company controls two power stations on the Ljungan, which provide 35,000 h.p., and also owns certain water-power rights.[1] Swedish water power is, on the whole, slightly more expensive than that in Norway; power is to-day produced in Trollhättan for about 50 kr. per kilowatt year. This small price difference, and the other general industrial conditions, have prevented the large-scale development of the arc process in Sweden, in spite of the close proximity to Norway. A nitrogen fixation process, due to Ph. Thorsell, was tried in an experimental plant in 1912 and found practicable; as a result, Aktiebolaget Kväfveindustri was founded at Göteborg in 1913, with a capital of 1,000,000 kr. in ordinary shares and 2,000,000 kr. in preference shares, to erect a works to operate the process at Bohus near Göteborg. The process depends on the intermediate formation

[1] K. Arndt, *Chem. Ind.*, 1919, Nos. 22-23.

of cyanide. In 1915 the capital was increased to 3·7 million kr., and in 1916 to 8,000,000 kr. After overcoming numerous technical difficulties, manufacture was started on the large scale at the end of 1914, but in December, 1915, a considerable portion of the plant was destroyed by fire. It was not possible to resume manufacture until the spring of 1916. Dearth of materials, due to the War, and manufacturing difficulties were so acute that in 1918 no product of the manufacture had yet been placed on the market. These works were originally planned to contain four batteries, each of four furnaces, each of which was to produce 1,500 tons of ammonium compounds per annum. Early in 1920 two of these furnaces were working. Apart from ammonium sulphate, alkali cyanides, oxalic acid, ammonium nitrate and other nitrates were to be produced. The company is the owner of a special ammonia oxidation process. An affiliated company, the A.B. Nitrat, with 140,000 kr. share capital, was formed in 1918. In order to deal with the dearth of raw materials, the A.B. Kväfveindustri also undertook the manufacture of soda by the old Leblanc process, but presumably this war-time industry will have to be relinquished, in consequence of falling prices and increased imports. Details of the Thorsell process are kept very secret, although considerable quantities of ammonium sulphate produced by the process have been marketed since the end of 1919. The plant is soon to be extended, as the management explained that they could maintain the cost of production at so low a figure that they could compete with every other nitrogenous fertiliser. According to the statement of the management, the expensive experiments which were carried on since 1912 enabled the process to be worked out satisfactorily in every detail. Unfortunately, towards the close of 1920 the works had to close, as it was practically impossible to carry out the proposed increase of capital.[1]

The process of the A.B. Cyanid was adopted by A.B. Trollhättans Cyanidverk, founded in 1916 with a capital of 500,000 kr. The A.B. Cyanid was formed in Stockholm in 1915 with a capital of 300 000 kr., in order to follow up on a large scale the experiments of Lindblad on the production of alkali cyanide, ammonia, etc., from alkali carbonate, carbon and nitrogen in the electric furnace (see German Patent 293,904), which were carried out at the Sandsta Elektriska Smältverk. The manufacture of other nitrogen compounds is also contemplated. A.B. Trollhättan Cyanidverk utilises 2,000 kw.

In 1916 A.B. Elektrosalpeter was founded in Stockholm with a capital of 3·2 million kr. to erect a works at Stallbäcken, near Troll-

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 460.

hättan, for the production, in the first instance, of 7,000 tons of concentrated nitric acid, and of sodium nitrate as a by-product, utilising the process of the Norsk-hydro (Birkeland-Eyde). The Swedish Waterfall Administration entered into a contract with the company, according to which the works of this latter should receive 12,000 kw. from the National Power Station at Trollhättan from January 1st, 1918. The result showed, however, that the working costs would be too high, owing to the excessive cost of power, to ensure profitable manufacture ; the agreement for power supply was therefore cancelled, and the works were not erected. Proposals to create an air nitrate industry in Sweden have, however, by no means been abandoned. On the contrary, the Government considers the stimulation of this industry to be extremely necessary, if only for considerations of national defence. It has, therefore, given the A.B. Elektrosalpeter a first call on 56,000 kw. from the first development of the proposed power station on the Harspranget Fall (105,000 kw.) and a further 18,000 kw. from the second development of this fall. The company proposes to produce 30,000 to 35,000 tons of calcium nitrate per annum, in order to cover the annual Swedish requirements. At the commencement of 1920 A.B. Elektrosalpeter had not yet decided whether it would utilise the Harspranget or the Porjus power station. The first development of the Harspranget Falls, which should have been completed by 1923–24, and for which 13,000,000 kr. were required in 1924 alone, has in turn been made dependent on the erection of works by the Elektrosalpeter Company

So-called "conversion saltpetre" is produced by the Gyttorp Powder Works, owned by the Nitroglycerin A.B. Apart from occasional announcements, nothing further has been heard of the new nitrogen fixation process of Dr. Tissell and Dr. J. Cederberg. Moreover, nothing further has been heard of the conclusions of the Commission of Experts appointed in 1919 to study methods of production and working costs of synthetic nitrate manufacture in Sweden.

A new ammonium nitrate explosive, called "normellit," was invented in 1915 by the engineer, Wulff Normelli. A more important development is that of C. Aberg, of Helsingborg, who proposes to utilise the carbon monoxide evolved in the production of carbide for calcining the necessary lime. It is said that the new process, which saves 70 per cent. of the fuel, could easily be installed at very slight expense.[1] A solution of this old problem, which is interconnected with the method of charging the furnaces, suitable methods

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 314.

of enclosing them and of freeing the gases from dust, is greatly to be desired.

A.B. Kväfvegödning of Stockholm, founded in 1915, is essentially concerned with the trade in nitrogenous fertilisers.

The industry of refrigeration and of liquefied and compressed gases is fairly well developed in Sweden; many experiments have also been made on blasting with liquid air. In 1917 the capital of the Solleftea Syrgasverk A.B. was 101,000 kr.

Sweden, which contains 52,000 sq. km. of moorland, has large peat resources, and the exploitation of these has been very greatly extended. According to investigations of the Peat Commission, 1,250,000,000 tons of air-dried peat could be obtained in Central and South Sweden alone. The development of the enormous moors of Norrland is difficult, on account of the short duration of the local summer; no suitable method of exploitation has yet been found for the extremely large district of Vitmossa in Central Sweden. In 1913 Sweden consumed 64,974 tons of peat and 2,216 tons of powdered peat. In 1916 these figures had altered to 84,330 and 1,188 tons respectively. In 1915 Svealand and Götaland produced 90,000 tons, in 1918 450,000 tons, and in 1919 350,000 tons of peat.

With regard to heating value, 400,000 tons of peat are approximately equivalent to 180,000 tons of coal. Sweden, therefore, offers a promising field for the gasification of peat, which has, as yet, hardly been attempted in that country. In 1918 the Sydsvenska Torfindustriförbundet was formed in Malmö with a capital of 2,000,000 kr.; this company owns moors in Schonen and Smaland. The administration of the Swedish State Railways has recently carried out experiments with a peat gas producer of C. G. Halberg, of Helsingborg, which are said to have been very successful.[1]

The distillation of oil shale has been undertaken, amongst others, by the A.B. Svenska Skifferverken, with a capital of 5,000,000 kr., at Lamma (Hidinge, in the parish of Nerika); for the present, this company proposes to treat 50,000 tons of shale annually. Nothing has so far become known with regard to the production of ammonia as a by-product. The shale deposits are said to be practically inexhaustible. The production of coal in Sweden in 1913 was only 320,000 tons.

Reports on the new plant of the Värta Gas Works in Stockholm are of much interest; it was decided to rebuild and extend the plant in 1913. The retort-house contains a battery of regenerative horizontal retorts with central generators on the Koppers system.[2]

[1] *Chem. Ztg.*, 1918, p. 439.
[2] Pamphlet of the firm of H. Koppers, 1920, No. 2.

The new ammonium sulphate plant deals with about 60 cu. m. of gas liquor, containing 2 per cent. of ammonia, per twenty-four hours. The wrought-iron saturator is not only lead-lined, but is also lined with a double layer of acid-proof stoneware. Pure sulphur is obtained from the waste gases by partial combustion in Claus ovens. The ammonium sulphate is hydro-extracted, and then transported to the storage bins by means of a bucket conveyor; the storage bins are constructed entirely of wood, and can be filled to the roof. The hydrogen sulphide evolved from the carbon dioxide separators is also converted into sulphur in Claus ovens.[1] The Swedish production in tons in recent years is shown in the following table:—

	1913.	1914.	1915.	1916.
Aqueous ammonia, calculated as 25 per cent.	760·0	729·9	827·3	1,145·8
Ammonium nitrate	649·3	561·8	618·8	684·1
Ammonium sulphate	1,376·7	1,510·3	1,613·7	1,340·3
Ammoniacal liquor	—	3,972·3	3,696·0	5,933·5
Calcium carbide	—	21,882·9	32,445·8	36,357·1
Potassium nitrate	—	—	—	181·6
Nitric acid, calculated as 100 per cent.	—	2,470·0	1,869·1	1,907·6
Compressed gases	1,166·9	—	—	1,486·2

The imports in 1913 and 1916 were as follows:—

	1913. Tons.	1916. Tons
Ammonium sulphate	37·8	1,402·1
Ammonium nitrate	62·4	148·4
Alkali cyanides	7·6	13·1
Compressed gases	34·6	23·4
Potassium nitrate	300·2	3·5
Aqueous ammonia	194·7	282·9
Nitric acid	87·6	2,729·5

The imports of Chile nitrate were: 35,107 tons in 1912; 33,892 tons in 1913; 41,694 tons in 1914; 1,298 tons in 1918; and 23,219 tons in 1919. The exports of carbide in 1918 were 2,784 tons; from January to October, 1919, the exports were 2,481 tons of carbide; the exports of calcium cyanamide were 385 tons in 1918 and 1 ton from January to October, 1919.

The carbide production of Sweden in 1918 was 51,000 tons, of which about 21,000 tons were utilised by the calcium cyanamide works for the production of about 27,000 tons of calcium cyanamide.

[1] *Journ. f. Gasbel*, 1918, pp. 205 *et seq.*

The Carbide Production Commission proposed to postpone the extension of the calcium cyanamide works, as such extensions would have been very expensive, and presumably their completion would have been long deferred. The remaining 30,000 tons of carbide are available for lighting, for industrial purposes, and for export. As, however, the total consumption for the latter purposes in 1918 and 1919 was 34,700 tons, the production is not nearly sufficient. In order, therefore, to increase the production, in 1918 the State appropriated the plant of the Vargöns A.B. at Rannum, which was manufacturing ferro-silicon for export, and converted it by August 1st, 1918, into a plant for the annual production of about 12,000 tons of carbide. The annual Swedish production of carbide should therefore now be about 63,000 tons. Before the War about 1,600 tons were exported per annum.

Before the War Norwegian nitrate was seldom imported, as it was burdened with an import duty of 15 per cent. This was removed in 1919. During the War international agreements between the Scandinavian countries ensured an annual delivery of 10,000 tons of Norwegian nitrate, and, in addition, Swedish agriculture was supplied, on the average, with 20,000 tons per annum of calcium cyanamide and other nitrogenous fertilisers produced within the country.

Prices were controlled by a National Economic Commission. In November, 1919, Norwegian nitrate cost 46 kr. per 100 kg., containing 13 per cent. of nitrogen, free at port of entry, whilst 100 kg. of Chile nitrate, containing 15 per cent. of nitrogen, cost 55 kr. Thus the price per kilogram of nitrogen was 3·54 and 3·67 kr. respectively. The price of Chile nitrate dropped in 1920 to 36 to 39 kr. per 100 kg. c.i.f. Gotenburg, or about 47 kr. per 100 kg., free delivery. In 1914 ammonium sulphate cost 24 kr. per 100 kg., and in 1920, to the agricultural consumer, 55 kr. In the chemical trade it cost as much as 95 kr. Ammonium nitrate varied in price from 52 kr. per 100 kg. in 1914 to 109 kr. in 1917, and 60 to 62 kr. in 1920.

The price of concentrated nitric acid rose from 30 kr. per 100 kg. in 1914 to more than 62·70 kr. in 1917, and 70 kr. in 1920. It is an interesting fact that in Sweden in 1918 Norwegian carbide was 50 per cent. dearer than domestic carbide. It cost $1\frac{1}{2}$ kr. per kilogram, compared with 1 kr. per kilogram for the Swedish product.

For spring deliveries in 1919 the kilogram percentage of nitrogen in calcium cyanamide cost 3·35 kr., whilst for autumn sales it cost 2·25 kr. Meanwhile the producers were guaranteed a considerably higher price by the State, namely 4·45 kr. per kilogram of nitrogen in August, 1919. The difference of 2·20 kr. is paid by the Government as a bounty, and this amounts to 39·60 kr. per 100 kg. of 18 per

cent. calcium cyanamide, or about 4,000,000 kr. in all for a total autumn delivery of about 10,000 tons. In 1920 the kilogram percentage of nitrogen in calcium cyanamide cost 2·95 kr.

The rapid industrial development of Sweden is also shown by the statistics of fresh capitalisation during corresponding half-years of 1917 and 1918; these were as follows:—

In the first six months of the year 1917:—
  625 new joint-stock companies, with about 188,000,000 kr. capital.

In the first six months of the year 1918:—
  745 new joint-stock companies, with a total capital of about 285,000,000 kr..

Supplement, 1921-24

Carbide production suffered through the bad exchange conditions, and the production was very much reduced, but the Alby Works (calcium cyanamide) have worked at full capacity since August, 1922, for the foreign market, and the Ljunga Works have worked at full capacity throughout (*Chem. Ztg.*, **1923,** 95, 479; *Chem. Ind.*, **1923,** 313, 378).

The smelting works of the Wargöns A.B. at Rannum are at present experimenting with a new method of cyanamide production due to Lidholm, for which licenses have been granted in Germany and the United States (*Chem. Ztg.*, **1922,** 215, 720; **1923,** 76, 248).

The A.B. Kväfve-Industri of Göteborg has not so far succeeded with the Thorssell method of fixing atmospheric nitrogen as cyanide, and went into liquidation in June, 1922. At the end of 1923 negotiations were undertaken for the sale of the foreign rights (*Chem. Ztg.*, **1922,** 624; *Chem. Ind.*, **1924,** 23).

The production in 1919 was 925 tons of ammonium sulphate and 13,115 tons calcium cyanamide. The exports in 1922 were 65 tons ammonium nitrate, 4,730 tons ammonium sulphate, 10,740 tons calcium carbide, and 3,689 tons calcium cyanamide. The imports were 20,179 tons Chile saltpetre and 17,640 tons Norge saltpetre.

CHAPTER VI

The Swiss Nitrogen Fixation Industry

In order to understand the present condition of chemical technology in Switzerland, one should first turn to the article by F. Winteler which appeared in the *Neue Züricher Zeitung* of 1918, Export Supplement No. 8 (February 27th, 1919).[1]

It is very obvious that the first necessity for a stable nitrogen fixation industry is cheap and abundant power, and it is equally obvious that in the case of Switzerland this can only be provided by the development of its waterfalls, the centralised exploitation of which has therefore been the aim of the Government.

Before the War the cheapest power stations in Switzerland cost 500 fr. per horse power, corresponding to a minimal price of 62·5 fr. per horse-power year. This figure is certainly more exact than that given by C. Dux in his book "The Aluminiumindustrie A.G. Neuhausen und ihre Konkurrenzgesellschaften," of 13 fr. per horse-power year, and only 200 fr. per horse-power installation costs. At a price of 62·5 fr. per horse power year the kilowatt hour costs about 1 centime. F. Winteler cites in his book for comparison a Norwegian nitrate works utilising 10,000 kw. Apart from the electric generating plant and working capital, but including cost of land, engineering works, building and internal construction, he estimates the cost to be about 4,000,000 fr. in all, or about 400 fr. per kilowatt—that is, 60 fr. per kilowatt year. The kilowatt hour thus costs 0·69 centime, that is, the 14,000 k.w.h. which are required for the production of one ton of concentrated nitric acid from the air cost 96·6 fr.

The other manufacturing costs, such as wages, repairs, packing, amortisation, administration, and so forth, amount to a total of 800,000 fr. for an installation consuming 10,000 kw. annually. The cost of production per ton of concentrated nitric acid in Norway is given at 300 fr., so that about one-third of this must be debited to the cost of power. Before the War the sale price of this acid was about 500 fr. Such a plant, therefore, would only seem to be profitable when the cost of a kilowatt hour was less than 2 centimes. The

[1] See also F. Winteler, "Die heutige industrielle Elektrochemie" ("The Present Industrial Electro-Chemical Industry") (Zurich, 1919, Rascher & Co.).

bases of these calculations are, of course, only approximately true to-day; but the values which are given still retain their importance as comparative figures, more especially as the individual factors can be applied in part to German conditions (2 centimes = 1·6 pfg. at pre-war rate of exchange, or about 14 pfg. at the rate of exchange of July 22nd, 1920).

In view of the fact that transport conditions in Switzerland are more favourable than those in Norway, a consideration of the abovementioned figures leads definitely to the conclusion that, under certain circumstances, even the arc process, with its very large demand for power, could be profitably worked in Switzerland; moreover, the further development of the water powers introduces numerous possibilities. But the high degree of development of Switzerland itself leads to various difficulties, in so far as the general economic interest is everywhere in conflict with the national appreciation of natural beauty, with feelings of attachment to the soil and with the interests of the tourist industry. The Falls of the Rhine could easily be further utilised, the Silser Lake in the Upper Engadine could be utilised, the Alpine Valley of Andermatt could be converted into a lake by means of a dam, a fall of 300 m. could be obtained from the Aegeri Lake by a tunnel through the Zuger Berg to the Lake of Zug, the Ritom Lake in the Canton of Tessin could easily be developed, and the conditions are also favourable in the case of the Mutt, Lungern and Stockhorn Lakes; numerous further instances of undeveloped water power could be mentioned. Many of these plans, such as the outlet from the south of the Silser Lake, which may be considered more or less as a high-level reservoir planned by Nature, would almost equal, in output and magnitude, Rjukanfos itself. A generally satisfactory compromise between regard for natural beauty, on the one hand, and the economically desirable utilisation of the water powers, on the other, has not yet been found, and few of these projects are likely to be developed in the near future. The development of the Ritom Lake alone is proceeding or finished. The plans for the development of the Aegeri or Silser Lake, or the damming of the Andermatt Valley, point to a price of about 300 fr. per developed kilowatt (1919)—that is, 0·5 to 0·6 centime per kilowatt hour—whereas, for example, the new power station at Eglisau provides power at 1,200 fr. per kilowatt, or 2 centimes per kilowatt hour. H. E. Fierz [1] estimates the total water power which could be developed in Switzerland at about 4,000,000 h.p., which is in agreement with the estimate of the Federal Hydrographic Bureau. [2] In general, Fierz takes a

[1] *Neue Zuricher Ztg. Exportbeilage*, Nos. 5, 6, February, 1919.
[2] *Ibid.*, Nos. 20, 22, May, 1919.

much less optimistic view of the future of the Swiss atmospheric nitric acid industry than Winteler. He prophesies " a gentle death " for the beautiful process of Serpek, which has been studied in Switzerland. Power requirements are as follows :—

	K.w h.
1 ton concentrated nitric acid .	13,000 to 14,000
1 ton calcium carbide	4,500
1 ton aluminium	35,000
1 ton sodium	17,000

In view of the lively interest with which these questions are regarded in Switzerland, the Year Books of the Swiss Wasserwirtschaftsverbandes (Water Power Association) are of special interest. In 1917 the Bernische Kraftwerke A.G. erected a ferro-silicon plant at Oey-Diemtigen, near their power stations at Spiez and Kandergrund ; under certain circumstances, this may at a later date be converted into a fertiliser works. The same firm is about to undertake an enormous new enterprise, the Grimsel Works,[1] which is to develop the water powers of the Aar, from its upper portion in the Haslital, and downstream as far as Innertkirchen. At the source the natural outflow of the Bächli glacier will be dammed, forming a lake of 3·2 million cu. m. available capacity. From there the water will flow into the large Grimsel Lake, which is to acquire an available capacity of not less than 55·6 million cu. m. This will be the largest collecting basin on the whole works, and will be produced by building a dam 150 m. long, 3·8 m. wide at the crest, 80 m. wide at the base, and 99 m. high. This dam will require 258,000 cu. m. of material. The water from the Grimsel Lake will flow to a power station at Guttannen, which is to supply approximately 120,000 h.p. The second stage is to feed a power station at Innertkirchen with approximately 90,000 h.p. The possibility of supplying seasonal power during four and a half months of the year has received special consideration. A further large water-power plant to supply 26,000 h.p. is to be built at Obertoggenburg and on the Walensee. The export of electrical energy to places abroad is controlled by an order of the Bundesrat of May 15th, 1918. An equalisation of the load, and a consequent utilisation of energy from these large electric installations, may, it is hoped, be provided by extension of the electro-chemical industries, with their uniform current requirements. In 1920 the Swiss power stations united to form the Schweizerischen Kraftübertragung A.G. and S.A. l'Energie l'Ouest Suisse.

The inaugural dissertation as Lecturer of Dr. C. A. Agthe in Zürich in 1918 on " The Importance of the Nitrogen Question and

[1] *Umschau*, 1920, p. 215.

its Solution in Switzerland," gives a broad outline of the development of the Swiss nitrogen fixation industry.[1] Before the War 2,000 to 4,000 tons of Chile nitrate were imported annually for Swiss agriculture (imports of Chile nitrate: 1913, 3,328 tons; 1914, 2,280 tons); there were also imported about 1,000 tons of nitric acid and 500 to 600 tons of nitrite for industrial purposes. The internal manufacture of nitrogen compounds was undertaken at a comparatively late date. The Aluminium-Industrie A.G., Neuhausen, were the first to produce nitric acid from the air in their works at Chippis by Moscicki's process. During the War a works was erected at Bodio by the Nitrum A.G., who manufacture nitric acid by their own process, and also small quantities of nitrate and nitrite. Bodio, in the Canton of Ticino, supplies dilute nitric acid only, which is concentrated for the manufacture of explosives at Chippis, near Siders, in the Rhone Valley. The production at both works was under the control of the Government. The requirements of the Munitions Section of the Swiss War Department could be readily covered, but considerable quantities for the purposes of private industry were only available after 1918. During the first half of 1914, there was a fairly considerable export of nitric acid, equal to the export of the previous year of about 1,000 tons, but naturally this was stopped at the outbreak of war. During the War nitrates were only produced in small quantities, although limestone deposits were available, and the sodium carbonate production of the works at Zurzach was being utilised for the production of synthetic nitrate. Although at that date nitric acid was the main product, for purposes of national defence, these conditions have completely changed in the interval, and nitrates are now produced.

The application of the Haber-Bosch process is not at present being considered, as it requires more fuel, and, moreover, electric power is of secondary importance only for the purpose. Whether the process may be adapted later to such different economic conditions is a question which need not be discussed here.

The calcium cyanamide process is more suitable for Switzerland, although it must be remembered that the necessary coke has to be supplied from abroad, and that considerable quantities of steam are required if the product is to be converted into ammonia.

Until direct methods of electrically heating steam boilers have been perfected, fuel is also necessary for this purpose. The poor supply of coal to the gas works and the small imports combine to

[1] *Chem. Ztg.*, 1918, p. 432.

make the synthetic manufacture of ammonium sulphate or other ammonium salts in Switzerland very desirable.

According to Agthe these conditions may render it advisable to examine a suggestion of Guye, who proposes to reduce nitrogen oxides with hydrogen at 250° to 300° C. to form ammonia,[1] using nickel as a catalyst. The economic feasibility of this process on a large scale still remains, however, to be proved.

The first producer of calcium cyanamide in Switzerland was the Société des Produits Azotés, of Paris, a French company, in a plant at Martigny on the Rhone, in Valais, which operates according to the Frank-Caro system, and had an output capacity in 1912–13 of 8,000 to 12,000 tons of calcium cyanamide. In 1913–14 the Elektrizitätswerk Lonza A.G. erected a works at Gampel, at the confluence of the Lonza with the Rhone, in Canton Valais, at which calcium cyanamide is manufactured by the Polzenius process. As is well known, the company is allied with the German nitrogen fixation interests through the plant at Waldshut. The Gotthardwerke A.G. für Elektrochemische Industrie at Bodio, on the southern slope of the Gotthard Railway (Ticino Valley, Canton Ticino), produce both ferro-alloys and carbide.

Nitrogen fixation by the arc process appears to be the method indicated for Switzerland, particularly in view of the possibility of producing ammonia and therefore ammonium nitrate by the Guye process. Extensions of the present installations are, however, necessary in order to cover the Swiss requirements for nitric acid, nitrates, and nitrite from internal sources. For this purpose about 35,000 h.p. would be necessary. Should the demand be doubled in course of time, 55,000 h.p. might suffice, whilst in 1918 a total of 500,000 h.p. was available. An additional 148,000 h.p. were in course of development on January 1st, 1918.

A consideration of Swiss conditions emphasises the vitality of the calcium cyanamide process, and also shows that under such conditions as hold in Switzerland, Norway or Sweden, the development of the Haber-Bosch process can scarcely be considered. For the supply of ammonia in these countries there remain the distillation of gas liquor, the gasification of peat, oil shale, etc., and finally the decomposition of calcium cyanamide, apart from any future prospects of the Guye process. The utilisation of electrically heated boilers, which must, however, necessarily work economically, or the discovery of methods of further transformation into products of a more favourable character from the point of view of heat economy

[1] *Helvetica Chemica Acta*, May, 1918; *Chem. Ztg.*, 1918, p. 273.

(production of urea, etc.), would be of great importance to the calcium cyanamide industry, and also to the newer cyanide processes.

The Aluminium Industriegesellschaft, Neuhausen, was formed in the year 1888–89 by the union of the Schweizerische Metallurgische Gesellschaft of Neuhausen, on the Falls of the Rhine, with the Allgemeine Elektrizitäts Gesellschaft of Berlin, directed by Emil Rathenau. In 1898 the new company was converted into a joint-stock company with a capital of 10,000,000 fr., which was raised in 1913–14 to 31,000,000 fr., and during the War to 52,000,000 fr. The net profits earned by these works in the last few years were very large.[1]

In 1905 the company acquired valuable water rights on the Rhone and on a small tributary, the Navigence, which flows into the former river opposite Siders. In order to utilise these water powers, the works at Chippis were built, which are the largest works of the Aluminium-Industrie A.G. According to K. Arndt, 100,000 h.p. are available at Chippis alone. In 1908 the Aluminium Industrie A.G. approached Ign. Moscicki with a view to the acquisition of his nitric acid process. In August, 1908, an agreement was signed in which Ign. Moscicki undertook to erect an atmospheric nitric acid plant, with accompanying absorption plant, for the production of 2,500 cu. m. per hour of nitrogen oxides from the electrical furnaces (I. Moscicki, "Nouveaux dispositifs d'absorption de grandes quantités de gaz," *Chim. et Industrie*). Towards the end of 1909, after overcoming initial difficulties, and as soon as it had been shown that the plant would work continuously with success, it was considerably enlarged. The concentration of the dilute nitric acid was found very troublesome, and a satisfactory method of concentration was only discovered after a considerable time. In 1915 the Nitrum A.G. was formed in Zürich; certain German companies, more particularly Griesheim-Elektron, took a leading part in its formation. The Nitrum A.G. has now a nitric acid plant at Bodio, which mainly produced dilute nitric acid during the War, but now manufactures calcium nitrate and sodium nitrate. An explosion occurred in 1921. As the manufacture of calcium cyanamide entails about 3½ kg. of coke per kilogram of fixed nitrogen, and the coke has to be imported into Switzerland, the production of nitrate from Swiss limestone and Zurzach alkali is in many respects more favourable. Towards the end of the War the works at Bodio increased their production by utilising additional water power from the Ritom Lake.

The history of the Swiss carbide industry starts as far back as

[1] K. Arndt, *Chem. Ind.*, 1919, Nos. 22–23.

1896, in which year the Aluminiumgesellschaft at Neuhausen built the first carbide furnaces. The first cyanamide factory was erected on the Rhone by the Société des Produits Azotés of Paris, and produced 8,000 tons of calcium cyanamide from domestic and foreign carbide in 1912. In 1913 the output was increased to 12,000 tons, but was, however, interrupted for a considerable period after August, 1914.

The electrical works of the Lonza A.G., Basle, was founded in 1898. Its foundation was due to the initiative of the Schuckertwerke, and started with the manufacture of carbide at Gampel on the Lonza and the Rhone. The directorate of the Lonza A.G. comprises six Swiss and three Germans. In 1917–18 the share capital amounted to 24,000,000 fr., of which the majority was in Swiss hands. The German capital was invested almost completely in the affiliated undertakings at Waldshut-i.-B. and Spremberg, whilst the remainder of the capital is predominantly Swiss, and to some extent French. In 1918 the company controlled more than 75,000 h.p., which is, however, to be greatly increased shortly.[1] There are works at Gampel, Thusis, Visp, Waldshut and Spremberg. Thusis and Spremberg are entirely devoted to the production of carbide; Gampel and Waldshut also produce calcium cyanamide by the Polzenius process; and Visp also produces considerable quantities of alcohol and so forth from carbide It is estimated that during the War about 60 to 65 per cent. of the output of Lonza was exported to the Central Powers.

The production of calcium cyanamide of the Lonzawerke Elektrochemische Fabriken G.m.b.H. at Waldshut-i.-B. was considerably extended with the help of financial support from the German Government. The Lonza A.G. of Basle were interested in these works to the extent of 4·65 million fr. in 1915–16. The works at Visp have been considerably extended during the last few years by means of an expenditure of 9,000,000 fr. Since 1917 they have produced alcohol, and since 1918–19 they have also produced acetic acid from carbide by the process of the Konsortium für Elektrochemische Industrie of Munich. The annual production of 7,500 tons of alcohol is to be increased to 10,000 tons. In September, 1919, the directorate inspected the new works on the occasion of their meeting at Brigue. At that time 100,000 litres of alcohol had already been manufactured. At a price of 45 fr. for coal at Visp, the Lonza A.G. is prepared to deliver to the Swiss Government absolute alcohol at a price of 555 fr. per metric ton. The Government has granted to the Lonza Works a concession for the manufacture of alcohol from

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 345.

carbide for the next twenty years. The manufacture of acetic acid has been carried on since November, 1917; 80 to 100 tons of acid of 99 to 100 per cent. purity are to be manufactured per month. In 1920 the Lonza A.G. met with difficulties due to the general economic position, and the plant had to be closed. The works at Thusis and the water-power rights in the Grisons have been acquired by a new company, the "Rhätische Werke für Elektrizität in Thusis." A transmission line runs from Visp to the Lake of Geneva. Manufacture of alcohol has been discontinued for the present on account of the enormously increased price of coal, but the manufacture of acetic acid and other products continues and is found to be profitable.

The Gotthardwerke für Elektrochemische Industrie of Bodio were financed by the A.G. Motor of Baden, Switzerland, and by a German group (Süddeutsche Diskonto A.G. and L. Weil & Reinhardt A.G. of Mannheim), both parties being equally interested. They produce almost the same series of products as the Lonza A.G.—namely, carbide, ferrosilicon, artificial abrasives, graphite, and so forth. By far the greater part of their products were exported to Germany.

During the time of the greatest coal famine, acetylene was used in Swiss gas works, either alone or mixed with wood distillation gases, in order to increase the gas supplies.[1] During the latter years of the War the use of acetylene for driving motors played a very important part in Switzerland, but then diminished, as liquid fuel, of which large quantities were once more available after the War, was ultimately found to be better. Keel [2] states that finally eight important works devoted themselves to the construction of acetylene motors, and that the Swiss Army Administration also studied these questions with great interest. A 30-h.p. four-cylinder motor of 100 revolutions required 260 litres of acetylene per horse-power hour. Both dissolved acetylene and acetylene gas were used, the latter being most carefully purified and filtered after production from carbide.[3] F. Haber has reported on similar experiments which were carried out by him on behalf of the Imperial German Board of Trade (25th Annual Meeting of the German Bunsen-Gesellschaft für angewandte physikalische Chemie at Halle-a.-S., April 21st to 23rd, 1920).[4]

K. Wolf, of Zürich,[5] recommends a mixture of acetylene and

[1] *Journ. f. angew.*, 1918, p. 465.
[2] "Das Acetylen im Automobilbetrieb" (Zürich, 1919).
[3] *Umschau*, 1919, p. 815.
[4] *Chem. Ztg.*, 1920, p. 339.
[5] *Ibid.*, 1919, p. 805.

oil gas for welding purposes. The internal Swiss production of oxygen, which was about 400,000 to 500,000 cu. m. in 1913–14, was considerably increased during the War by the erection of many new works.[1] A new cyanide process has been developed by A. V. Lipinski,[2] of Baden, Switzerland, and is said to be very promising.

Switzerland contains about 250 moors, of which, however, very few are of any considerable area, and of which many have already been exploited. The supply of peat still available for exploitation is estimated to be about 65,000,000 cu. m., or 13,000,000 to 22,000,000 tons of air-dried peat. The production of peat during the War met with serious difficulties, arising mainly from a lack of suitable machinery and labour. Conditions commenced to improve, however, in the spring of 1919, so that in 1919 1·5 million cu. m. or 300,000 to 500,000 tons of peat fuel, with 10 to 30 per cent. of water, were obtained. In this way 17 to 18 per cent. of the annual Swiss demand for fuel was supplied.[3] A Swiss Peat Association (Schweizerische Torfgenossenschaft) was formed in April, 1917, and in 1918 it received from the Government a loan of 5,000,000 fr. for the purpose of exploiting twenty-four of the larger moors. Apart from this association, there are many individual enterprises, such as the Aargauische Torfgesellschaft, the Torfgesellschaft "Union" of Berne, the Torfgenossenschaft des Bezirkes Affoltern and others. Since April 1st, 1918, the control of all peat deposits and of the trade in peat has been vested in the Swiss Inspectorate for Forests, Game and Fisheries, which has fixed maximum prices. The analysis of twenty Swiss peats of the most various origin showed ash contents of 3 to 41 per cent. and calorific values of 1,700 to 4,600 calories per kilogram.[4] Nothing has been heard with regard to the gasification of peat with nitrogen recovery.

The enormous development of industrial electro-chemistry in Switzerland [5] is more particularly indicated by the statistics of the carbide industry, which produced 4,000 tons in 1901, 30,000 tons in 1912, 35,000 to 40,000 tons in 1913, 72,000 tons in 1917, and 95,000 tons in 1918. The internal consumption in Switzerland has increased from 4,000 tons in 1912 to 16,000 tons in 1918. In 1918 Swiss agriculture utilised about 10,000 tons of calcium cyanamide. The sale of carbide is regulated by an ordinance of the Swiss Board of Trade of November 9th, 1918. Prices increased from 20 fr. per

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 509.
[2] *Chem. Ztg.*, 1917, p. 166.
[3] *Neue Züricher Ztg.*, July 8th, 1919; *Zeitsch. f. angew. Chem.*, 1919, ii., 147.
[4] *Neue Züricher Ztg.*, July 8th, 1919.
[5] F. Winteler, *Chem. Zentralbl.*, 1919, iv., 653.

100 kg. before the War to 56 to 59 fr. in 1918 and 51 to 55 fr. in 1919, according to the quantity delivered without packages (drums, 6 to 10 fr.) f.o.r. for internal consumption. The calcium carbide exports in tons during the last few years to various countries were as follows :—

	1913	1914	1915	1916	1917.	1918.
To Germany . .	25,013·2	29,583·9	48,633 7	46,261·9	37,843·0	44,210·9
,, France . . .	35·7	21·6	9 9	10,360·5	17,108·9	29,870·0
,, Austria-Hungary .	—	242·1	20·0	40·0	3,940·8	—
,, Bulgaria . .	—	—	39·9	300·0	453·5	630·0
,, Belgium .	2,349·7	1,380 5	3,910·2	690 4	—	700·0
,, Holland. . .	2,671·0	3,397·1	2,219·2	20·0	—	—
,, Portugal .	1,630 0	1,300 0	—	—	—	—
Total .	31,790·4	35,950·5	55,412 5	58,009·8	59,447·6	57,837·4

The share of Germany in the Swiss exports of carbide, which was already very considerable before 1914, has increased again in actual quantity, but has decreased relatively in favour of exports to France. Before the War France itself exported considerable quantities of carbide, but, in consequence of the enormous consumption during the War, has been forced to supplement its requirements by imports from Switzerland.

The exports decreased heavily in 1919 :—

	Swiss Exports, in Tons		
	1913.	1918	1919.
Aluminium	6,891·1	10,521·6	5,245·7
Calcium carbide . . .	31,790·4	75,840·0	36,891·6
Ferro-silicon and ferro-chrome.	16,175·3	15,666·7	9,741·5

The Swiss output of aluminium was about 12,000 to 15,000 tons in 1917, of which 86 per cent. was exported. The manufacture of carborundum, abrasives, etc., in 1917 was estimated to be 3,000 to 4,000 tons.

The imports of saltpetre, ammonium sulphate, technical ammonium salts, etc., were 258·8 tons, valued at 201,000 fr., in 1917, and 540·6 tons, valued at 540,000 fr., in 1918.

The following Swiss trade statistics are expressed in tons and valued in thousands of francs (in brackets) :—

	Imports.				
	1914	1915	1916	1917	1918
Compressed acetylene .	1·0 (0·7)	1·2 (0·8)	15·4 (120·0)	23·8 (214·0)	– –
Compressed ammonia, liquid	1·7 (3·7)	— —	— —	— —	– –
Calcium carbide . .	37·6 (8·3)	2·6 (1·0)	10·7 (9·1)	— –	1 —
Potassium and sodium nitrate, pure.	562·8 (478·4)	13·4 (29·1)	534·9 (753 5)	383·9 (471·0)	390·2 (443·0)
Sodium nitrite . . .	31·4 (16·9)	1·1 (0 7)	240·8 (240·0)	416·4 (731·0)	454·1 (886·0)
Ammonium chloride . .	219·4 (131·6)	69·4 (45·1)	76·8 (69·1)	119 7 (208·0)	180·5 (354·0)
Aqueous ammonia . .	135·1 (43 2)	28 7 (11·5)	0 2 (0·1)	31·3 (25·0)	– –
Nitric acid. . . .	127·7 (48·5)	13 7 (10·3)	294 3 (322 0)	349·0 (361·0)	- -

	Exports				
	1914	1915	1916	1917	1918
Compressed acetylene. .	3·5 (3·7)	3·7 (3·8)	1·3 (1·3)	— –	– –
Compressed ammonia, liquid.	3 9 (8·4)	6·3 (28·0)	14 3 (44·0)	9·4 (37 8)	- –
Calcium carbide . .	35,950 5 (7,834·0)	55,412·5 (12,484·0)	58,009·8 (17,378·0)	59,447·6 (20,942 0)	75,837·4 (35,206·0)
Potassium and sodium nitrate, pure.	1·5 (1·0)	14 5 (22·5)	— —	– -	— -
Sodium nitrite . . .	240 9 (80·1)	255 0 (127 5)	143·7 (75·6)	49·4 (41·0)	- -
Ammonium chloride . .	0·7 (0 5)	4·1 (3·5)	0·4 (0·5)	0·1 (0·2)	-
Aqueous ammonia . .	94·9 (32·1)	243·7 (84·3)	74 4 (44·5)	365 2 (208·0)	– –
Nitric acid. . . .	679·1 (293·8)	660·9 (426·1)	11·0 (8·5)	0·1 (0 1)	— –

The output of calcium cyanamide was particularly large in 1917, and greatly exceeded the output of 1916. In 1918 there were already complaints of the decreased demand. During the War the carbide

works were fully occupied. The economic result would have been still more satisfactory if the cost of production had not been greatly increased and the inferior quality of the raw materials had not resulted in less satisfactory outputs from the furnaces. At the close of the War the prospects of the carbide industry were supposed to be favourable, although it was feared that the carbide works would not be so prosperous as hitherto, as the demands of the calcium cyanamide works and the acetylene industry would certainly not suffice to keep them fully occupied indefinitely. They also had to reckon with greatly increased competition from abroad, as carbide works were established everywhere in consequence of the War.

So far a pessimistic view of the position of the Swiss carbide industry has proved to be justified. For the most part manufacture can only be maintained on a greatly diminished scale, and a number of works have had to close down entirely. Coke and anthracite are often unobtainable and the sale of carbide is also attended with difficulties. Export is hardly to be thought of. France imposes a duty on carbide of 1,500 fr. per truck-load, and 5 fr. per drum, so that a truck of carbide sent to France has to pay a duty of 2,000 to 2,200 fr. Exports to Germany and Austria are quite impossible on account of the rate of exchange, for in the middle of 1920 100 kr. were equal to 3 to 5 fr. There is no indication of a recovery for the present. Profitable export would only be possible should the foreign exchanges improve. The domestic Swiss consumption is capable of a gradual increase.

The Schweizerische Agrikulturchemische Anstalt Oerlikon-Zürich and the Schweizerische Samenuntersuchungs und Versuchsanstalt Oerlikon-Zürich were amalgamated on January 1st, 1920, under the name of Schweizerische Landwirtschaftliche Versuchsanstalt Oerlikon-Zürich. This organisation is devoted to the study of fertilisers.

Supplement, 1921-24

The carbide industry is very depressed. Whilst the output capacity is 120,000 tons, the maximum home demand is 10,000 tons, and the exports were only 9,262 tons in 1922 and 1,629 tons in the first half of 1923 (*Chem. Ztg.*, **1921,** 79; **1922,** 1007–8; *Chem. Ind.*, **1923,** 133, 382, 519, 536; *Metallbörse*, **1923,** 906, 1339–40).

The Bodio Works of the Nitrum Company in Zürich, which exploits Siebert's arc process, suffered from an explosion in its plant for freezing out nitrogen peroxide, in which benzine was used as a cooling liquid (*Chem. Ztg.*, **1923,** 63; *Zeitsch. f. angew. Chem.*, **1923,** 87; *Chem. Ind.*, **1923,** 583).

The Martigny Works of the Société des Produits Azotés manufacture calcium cyanamide and a new fertiliser known as phosphozate, according to patent rights belonging to the parent company in France, and also to the French Société d'Electrochimie. This material contains 11 per cent. of water-soluble phosphoric acid and 11 per cent. of urea (*Chem. Ztg.*, **1922,** 823).

The Aluminium Industrie A.G., Neuhausen, suffered from difficulties of water supply and from strikes at their nitrate works at Chippis in 1922 and 1923 (*Metallbörse*, **1923,** 811).

The Lonza A.G. closed their business year with a loss of 678,255 fr., but this crisis may have been overcome in the interval, and the affiliated companies achieved more favourable results. The synthesis of alcohol, and more particularly of acetic acid, has met with increasing success. Licenses for these processes have been granted to Acetosynthèse of Paris, who also intend to utilise carbide. The demand for calcium cyanamide appears to be increasing in spite of the fact that the German branch factory at Waldshut has been closed down for a considerable period. The production of ammonia by the Casale synthetic process is to be undertaken at Visp in conjunction with another Swiss group (*Metallbörse*, **1923,** 2347, 2467).

The total production capacity for calcium cyanamide is probably about 40,000 tons.

CHAPTER VII

The Nitrogen Industry in the Austrian Succession States[1]

THE conditions of electrical supply in German-Austria are worthy of special attention, as it would be possible for the country to supply its whole power requirements. Under pre-war conditions the annual coal requirements were about 12,500,000 tons. The domestic production is now about 2,000,000 to 2,500,000 tons, so that a deficiency of 10,000,000 tons should be supplied by imports, corresponding to an energy production of about 1,000,000 h.p. for 6,000 working hours per year. This supply of energy could easily be derived from water power. According to the work of the Research Board of the former Railway Ministry, there are more than 1·3 million h.p. available in German-Austria, for the exploitation of which 266 power stations would have to be constructed. The actual power which could be developed from the Alpine water powers of Austria by practicable works is, however, estimated at almost 2,500,000 h.p. Of this quantity only 250,000 h.p., or about 10 per cent., has already been developed, so that large sources of energy are available which are certainly destined to play a future part in the nitrogen fixation and electro-chemical industries. In Styria, in particular, it has been proposed to utilise water powers in connection with the iron industry.[2]

It has been proposed that the electric industry should be so organised that a national electricity undertaking should be established, in which the State should participate. In order to attract foreign capital, concessions could be granted to constructional and industrial companies. It would be impossible to finance the project internally, as thousands of millions would be required ; moreover, constructional materials, such as cement, transmission lines, etc., are lacking. In order to facilitate the co-operation of the State and district administrations, a Water Power and Electric Supply Board (W.E.W.A.) has been formed.[3]

The Austrian Government and the municipality of Vienna are to exploit the water powers of the Enns, estimated at 60,000 h.p., at a

[1] German-Austria, Hungary, Czecho-Slovakia, Jugo-Slavia and Poland.
[2] *Metallborse*, 1920, p. 1395.
[3] *Sudd. Ind. Blatt*, 1920, p. 1339.

cost of 80,000,000 kr. The Steiermärkische Wasserkraft und Elektrizitäts A.G., founded in 1919, was formed for the purpose of developing the Styrian water powers. Its capital is 20,000,000 kr., but may be increased to 100,000,000 kr. The Tramway und Elektrizitätsgesellschaft Linz has held a concession since 1919 for the exploitation of 28,000 h.p. (which will cost from 14.000,000 to 15,000,000 kr.) on the Grosse Mühl from Neufelden to Neuhaus in Upper Austria. Meanwhile the Oberösterreichische Wasserkraft und Elektrizitätsgesellschaft in Linz has been formed by the cooperation of the Österr. Waffenfabriks-Ges., the Province of Upper Austria, and the Austrian Government; this has a capital of 50,000,000 kr., of which the Treasury has taken over one-fifth. The Kleine Mühl is to be developed at a cost of 200,000,000 kr.

The first atmospheric nitric acid works on Pauling's system (see previous account of the German industry) was installed at Patsch, on the Sill, and utilises 15,000 h.p. from Innsbruck Power Station. The current is transformed down from 10,000 to 4,000 volts, and then serves to operate 24 Pauling furnaces, each containing 2 arcs. There are 3 furnaces in each group. One man is required for each 6 furnaces. The Patsch Works of the Luftverwertungsgesellschaft Innsbruck has rendered valuable service in the development of the Pauling process; for the present it utilises 70,000,000 k.w.h. per annum, supplied by the Innsbrucker Elektrizitätswerk (Innsbruck Power Station) at an exceptionally low price, to manufacture about 5,000 tons of concentrated nitric acid per annum. On the other hand, the nitric acid works benefit the Innsbruck Power Station by consuming its surplus energy at times of small load. Before the War it was intended to add a carbide works with an output of 8,000 tons per annum, and a cyanamide plant, in order to utilise the energy still more effectively. The economic success of the installation, the position of which was described as favourable in 1916, has not, on the whole, been very remarkable, as is clear from the report of the Internationale Stickstoff A.G. in Wiesbaden. There is another works at Matrei, 10 km. further up the Sill, producing carbide, ferro-alloys, etc.

During the War the same causes as were operating in Germany led to the erection of nitrogen fixation plants in Austria; the first of these was erected on the property of the Government Explosive Works at Blumau, near Vienna. This works produces calcium cyanamide by the Frank-Caro process, and has an important ammonia oxidation plant. Together with a portion of the explosive works it has latterly been taken over by a combine, at the head of which is the Vienna branch of the firm of J. Michael & Co., of Berlin

and Vienna. A portion of the works is still carried on jointly with the Government as an undertaking under dual control for the manufacture of organic products and dyestuffs, with a capital of 6,000,000 kr.[1] On July 30th, 1920, a joint-stock company was formed, which included the explosives works, Skodawerke, Wetzler A.G., and the Government Works at Blumau. This has a capital of 4,000,000 kr., and has remodelled a number of the installations at Blumau for the production of inorganic chemicals.[2]

In 1916 the Österreichischen Stickstoffwerke A.G. was founded by the Niederösterreichischen Eskompte-Ges., the Allgem. Depositenbank, the Bosnischen Elektrizitäts A.G., the Dynamit Nobel-Ges., and the Prager Eisenindustrie A.G., with a capital of 10,000,000 kr. The calcium cyanamide works, Maria-Rast, near Marburg (Styria), were to have commenced production in 1917, but only did so in July, 1918. The carbide works were complete at the commencement of May, 1918, and then awaited the official authorisation to obtain the necessary raw materials. The estimated constructional costs were largely exceeded, so that new shares had to be issued, to which the State contributed 2,500,000 kr.

At the end of 1917 there was founded in Vienna the "Institut für Kohlenvergasung und Nebenproduktengewinnung" to study the fixation of nitrogen from coal and similar questions. Its first communication in 1918 contained an interesting article by F. Dörner on ammonia as a by-product of the gasification of coal.

Much attention has recently been devoted to the Austrian peat industry. In 1918 the Salzburgische Torfwerke G.m.b.H. was founded with 1,000,000 kr. capital at Lamprechtshausen (Salzburg). The Government Department for Trade and Industry, in co-operation with the Vereinigung der Deutsch-österreichischen Industrie, founded the Deutsch-österreichische Torfindustrie-gesellschaft, with headquarters in Vienna, in accordance with the peat production law of 1919. The company has a monopoly in so far as it has the sole right to apply the law for the compulsory acquisition of peat moors, and has also a monopoly of the right of exploiting the same. As an undertaking under divided control, the company is excluded from socialisation. Of the share capital of 4,000,000 kr., 1·35 million kr. are private property. In 1920 the Vienna firm of Suchy-Werke A.G. acquired important oil shale deposits in North Tyrol, which were expected to yield 100 tons of crude oil per month.

The proposal to syndicalise the nitrogen industry and to form a Wirtschaftsverbande der Kunstdüngerindustrien in Österreich

[1] *Metallbörse*, 1920, p. 725.
[2] *Ibid.*, 1920, p. 1251.

("Trade Association of Austrian artificial fertiliser manufacturers") on August 8th, 1918, was part of the pre-revolutionary programme. In an article well worth attention in the *Neue Wiener Tageblatt* of May 24th, 1919, a carbide monopoly for Austria is recommended to deal with the utilisation of all surplus power and the development of water power on a large scale.[1] The official carbide prices of the Central Price Fixation Commission of May 1st, 1918, were 85·90 to 90·90 kr. per 100 kg., according to size of delivery, granulation, etc.

These prices were based on a price for limestone of 6·10 kr., and for coke of 17·52 kr. per 100 kg. The proportion of the output due to works in the Alpine district was at that time 24 per cent., and that of the Dalmatian Works, 76 per cent. If the proportion of the output of the Alpine Works increased, the official prices became more moderate ; if this proportion decreased, then the official prices increased by 10 heller per 100 kg. of carbide for each 1 per cent. of this increased proportion of delivery. These latter decisions are interesting in so far as they show that the Alpine Works have lower working costs than those in Dalmatia, which is due in part to their more favourable situation with regard to transport.

The occurrences of natural gas in Transylvania are of great importance for the industrial development of Hungary. They were discovered in 1908 whilst prospecting for potash salts. By testing the gas wells it has been found that these could deliver 2·4 million cu. m. of gas per day if allowed to flow freely. In 1911 the right to develop and utilise these wells was monopolised by the Government. In 1912 an English financial group had the intention to utilise the natural gas resources, which were estimated to amount at that time to 72,000,000,000 cu. m. of 8,000 calories thermal value, corresponding to 100,000,000 tons of coal of 6,000 calories. The negotiations failed, and it was only in the War period that the project was realised on a large scale by "Ungarische Erdgas A.G., Budapest," founded in 1916 in Berlin, with the assistance of the Deutsche Bank, as a result of a small preliminary development in the interval. In 1916 1 cu. m. of natural gas from the Hungarian wells cost 15 heller, gas for domestic purposes 10 heller, power gas for small motors of less than 25 h.p. 6 heller, and industrial gas 4 heller at the locality where used. The towns of Kolozsvár, Medgyes, Dicsöszentmárton, Torda, and others, are connected to the gas-field by long-distance mains. Since the spring of 1913 the ammonia-soda works at Torda and the cement works at the same place have been worked by natural gas. In 1917 there was even a project for the construction of a gas main, 450 km. long, to Buda-Pest.

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 385.

A gas main from the natural gas wells at Magyarsáros supplies the large cyanamide works at Dicsöszentmárton, which is the property of the Ungarischen Stickstoffdünger Industrie A.G., founded in 1916 with a capital of 9,000,000 kr., which was later increased to 15,000,000 kr. The "Holzverkohlungs A.G. Konstanz," participated in the increased capitalisation to the extent of 750,000 kr. This amount was increased at a later date proportionally to the increase of the total capital from 9,000,000 to 15,000,000 kr. The works played scarcely any part during the War.

This is also true of the Ungarnwerk at Magyarovar (Hungarian Altenburg) at the confluence of the Leitha with the Lesser Danube, which is also equipped for the production of cyanamide and its derived products. In consequence of the decline in stock-raising, the requirements for artificial fertilisers in 1920 were extremely large, and the few works in actual operation are incapable of supplying the demand. Imports from abroad are hardly possible. At present the only producing carbide works are the Felsogalla Works of the Ungarische Allgemeine Kohlenbergbau A.G., with a daily production of eighty truck-loads, which uses charcoal instead of coke.

A company with 2,000,000 kr. capital was founded by a number of firms in 1918 for the purpose of studying the water-power resources of Hungary, which have as yet scarcely been utilised. There are several oxygen works in Hungary, at Buda-Pest, Temesvár, Nagyvárad and other places.

In 1916 the Buschtiehrader Railway of Vienna and the Österreichische Verein für chemische und metallurgische Produktion of Aussig, on the Elbe (now the A.G. für chemische und metallurgische Produktion in Karlsbad), co-operated with the Allgemeine Österreichische Bodenkreditanstalt to acquire the hitherto unworked coalfield of Lastner in the Falkenau district, not far from Karlsbad, under the name "Falkenauer Kohlenbergbau A.G.," with a capital of 2,000,000 kr., the shares of which were divided equally between the Buschtiehrader Railway and the Aussig Company. Simultaneously the erection of a cyanamide works was commenced at Falkenau on the Eger, which commenced operation at the beginning of 1918. The cost of this works was estimated in 1917 at 20,000,000 to 22,000,000 kr. At a later date carbide alone was produced, and only in 1920 was the production of cyanamide again taken in hand, in order to supply the agriculturalists of Czecho-Slovakia. Carbide has also recently been manufactured at the Weinmann Works at Schwaz (Bohemia),[1] and the Witkowitz Colliery in Moravia is erecting a works for the production of liquid ammonia.

[1] *Chem. Ztg.*, 1920, p. 264.

The lively interest which has always been shown in the development of the nitrogen industry in the countries now united to form Czecho-Slovakia, was indicated by the Bohemian Academy of Science at Prague, by the offer of a prize of 5,000 kr. in 1916 for the best communication on the utilisation of atmospheric nitrogen. It has recently been stated that experiments at the sugar factory at Pecek on the manufacture of ammonia and nitric acid from the nitrogenous contents of the effluent from sugar works, has been so successful that 600 to 700 tank loads of nitric acid are produced annually by this means in Czecho-Slovakia. The united tank and condenser liquors contain about 65 mgm. of nitrogen per litre, of which 34 mgm. are present as ammonia, and 31 mgm. as organic compounds, and 13 cu. m. of these liquors are obtained per ton of beet, corresponding to a total of 845 gm. of nitrogen. The total crude sugar production of Czecho-Slovakia is now about 750,000 tons, corresponding to about 4·65 million tons of beet. According to these figures, the total effluent waters already referred to would contain about 3,900 tons of nitrogen ; 6,000 tons of synthetic nitrate contain about 950 tons of nitrogen. The above-mentioned figure of 65 mgm. per litre[1] can naturally not be considered as representative, as the composition of the effluents varies extraordinarily, as is shown by the collection of analytical data which was made by Ferd. Fischer.[2] In any case, the calculation shows that the nitrogen balance may be correct on the assumption that it will be possible to obtain all the fixed nitrogen in the form of NH_3, and carry out all the further transformations without loss. Even if all this were true, however, the process could hardly work economically. The distillation of ammoniacal liquor of such dilution is quite possible in ammonia distillation columns, as good columns yield effluents containing only 1 to 3 mgm. of NH_3 per litre, but the steam consumption is so high that the ammonia would be very expensive. So long, therefore, as no better methods of treatment are available, such processes will hardly be profitable Moreover, similar experiments have been tried elsewhere, and have not been successful.

As the domestic production of nitrogenous fertilisers is insufficient, the republic of Czecho-Slovakia imports Chile nitrate from Hamburg, more particularly for the beet sugar industry ; 14,000 tons of Chile nitrate were imported for use in the spring of 1920 ; in addition 5,000 tons of superphosphate were produced from domestic, and 6,800 tons from foreign raw materials for the fertilisation of the beet crops. Superphosphate containing 18 per cent. of water-

[1] See Vogel, " Abwasser " (Ullmann's " Encyclopædia," i., 1914, p. 41).
[2] " Das Wasser " (Leipzig), 1914, pp. 232–252.

soluble phosphoric acid cost 180 kr. per 100 kg. at works, whilst 100 kg. of Chile nitrate cost 480 to 500 kr. (gross weight) at Czecho-Slovakian frontier stations.

In 1919 the Aussiger Verein (see p. 162) established an advisory bureau for nitrogenous fertilisers for the agriculturalists of Czecho-Slovakia at Jundorf near Brünn, directed by Dr. H. Lipschütz. In 1919–20 an agreement was arrived at between the Czecho-Slovakian Republic and a North American firm for an exchange of commodities, including the despatch from Czecho-Slovakia of 10,000 tons of carbide.[1] The official prices for carbide, which had previously been 3·0 to 3·25 kr. per kilogram, were raised as from April 1st, 1920 to July 31st, 1920, as follows :[2] If delivered in railway trucks from the Falkenau Works, 5 kr. per kilogram ; from the Weinmann Works, 5·30 kr. per kilogram at works ; in the retail trade an additional charge of 0·25 kr. to 0·30 kr. per kilogram, and a 5 per cent. discount for dealers are allowed.

The waterfalls of the Dalmatian Cetina, which are 48 m. high and could supply about 80,000 h.p. when the water is lowest, are only exploited to the extent of about 20,000 h.p. The A. G. zur Nutzbarmachung der Wasserkräfte Dalmatiens (Joint-Stock Company for the Utilisation of the Water Powers of Dalmatia) was founded for the manufacture of carbide at Almissa and cyanamide at Sebenico. These works were erected before the War by the Società Anonima per la utilizzazione delle forze idrauliche della Dalmazia of Trieste ; they operate the Frank-Caro process. The production of cyanamide in Sebenico during 1912 and 1913 was 5,000 tons per annum ; no figures are available concerning Almissa. Before the War these were the only works in Austria-Hungary to utilise atmospheric nitrogen, apart from the atmospheric nitric acid works at Patsch, near Innsbruck. The Dalmatian Company was unable to pay a dividend during the War on account, it is said, of unfavourable sale contracts. In 1918 their capital was raised from 14,000,000 to 21,000,000 kr. Carbide and other electro-chemical products are also manufactured by the Bosnian Electric Company at Jajce. An aluminium works was to have been established in 1916 for the exploitation of the bauxite deposits at Bruvno, near Rudopolje, in the Lika, Croatia, and this was also to have produced 60,000 tons of aluminium nitride annually as a by-product. Power was to have been produced from the lakes of Plivitz, which are 50 km. distant. Nothing further has been heard of this project. In 1905 540,000 tons of coal were produced in Bosnia.

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 26.
[2] *Chem Ztg.*, 1920, p. 455.

In 1918 the Government sanctioned the formation of a joint-stock company for the production of nitrogenous fertilisers by the process of Moscicki of Cracow. The initial capital was 3·5 million kr., of which 2,000,000 kr. were provided by the Government Department for the Economic Recovery of Galicia. The remainder was supplied by the Galizische Landesbank and other interested parties. The company, known as the Galizische Stickstoffdüngerfabrik Azot A. G., now the Towarzyostwo-Akcyjne "Azot," is erecting a works at Bory, near Jaworzno. Jaworzno is a station on the railway between Szczakowa and Chrzanów, in Poland, where there are large coal mines, and lies about 10 km. to the south-east of Myslowitz. The works were to have started production in October, 1918, but in consequence of unfavourable circumstances have not been started yet. About 7,000 kw. are available. Ammonium nitrate and concentrated nitric acid are to be produced, and 800 tons of combined nitrogen are to be supplied annually (equal to about 3,400 tons of ammonium nitrate) from gas liquor and atmospheric nitric acid, or 4,000 to 4,500 tons of concentrated nitric acid. The Moscicki furnaces of the installation at Bory-Jaworzno are described in German Patent 265,834.

As an example of the trade under pre war conditions, we give import and export statistics of Austria-Hungary for the year 1911 :—

	Imports. Tons.	Exports. Tons.
Liquid carbon dioxide	85·3	78·4
Ammoniacal liquor :		
Concentrated	553·2	18·8
Unconcentrated	-	694·1
Ammonium carbonate	225·1	92·6
Liquid ammonia	34·7	125·0
Chile nitrate	65,781·4 (93,025 in 1913)	325·4
Ammonium sulphate	8·0	20,026·7
Ammonium chloride	904·1	8·0
Ammonium carbonate	79·4	1·8
Ammonium acetate	0·1	2·8
Potassium and sodium nitrates (refined)	9·6	64·4
Sodium nitrite	59·5	116·8
Potassium ferro- and ferri-cyanide	12·7	26·3
Ammonium sulphide and ammonium nitrate	397·2	0·1
Carbide	3·8	11,723·7

The production of coal, lignite and coke was as follows, in thousands of tons :—

	1900.	1905.	1910.	1913.
Coal	12,440	13,673	15,171	17,760
Lignite	26,668	28,781	32,792	35,878
Coke	1,228	1,400	1,999	2,700

Supplement, 1921-24.

German-Austria.—The Kontinentale Stickstoff A.G. of Munich, already referred to in connection with the German industry, are erecting an atmospheric nitric acid works at Golling, near Salzburg. The country produces 160,000 tons of coal and 3,110,000 tons of lignite, and imports 4,020,000 tons of coal and 390,000 tons of coke. The exports in 1921 were 3,227 tons of calcium carbide, 260 tons of sodium nitrite, and 1,144 tons of nitric acid (*Chem. Ztg.*, **1921,** 716; **1922,** 232, 332, 604, 691, 1100; **1923,** 399; *Chem. Ind.*, **1923,** 611; *Metallbörse*, **1923,** 616).

Hungary.—The carbide works (*e.g.* Felsogälle) are working intensively. The former explosive works Maggazovas have been adapted to other manufactures (*Chem. Ztg.*, **1922,** 110; **1923,** 95; *Chem. Ind.*, **1923,** 651).

In *Poland* the nucleus of manufacturing activity is provided by the former German coke ovens of Upper Silesia and the calcium cyanamide works at Chorzow in the same region, which were built by the German Government. The activities at Chorzow are being carried out with difficulty and unprofitably in the absence of trained German staff.

The chemical works "Azot" at Borry (Galicia) produce, among other products, nitric acid from the air by the Moscicki process. Poland produced in 1922 35 million tons of coal, of which 26 million tons came from Upper Silesia; and contained 120 chemical works, most of which were in former German territory (*Chem. Ztg.*, **1923,** 512, 620; *Chem. Ind.*, **1923,** 69, 119, 317, 376, 490; **1924,** 23; *Metallbörse*, **1923,** 1607, 1951, 2048; **1924,** 140).

Czecho-Slovakia has both coke ovens and a calcium cyanamide works at Falkenau. In 1922 it imported 24,354 tons of Chile nitrate (*Chem. Ind.*, **1923,** 222, 498, 614, 682; **1924,** 34; *Metallbörse*, **1923,** 1099, 1369, 1760, 1882).

In *Jugo-Slavia* the manufacture of carbide and calcium cyanamide is highly developed. The works at Jajce have a production capacity of 900 tons of carbide per month: at Kus, 27,000 tons of carbide

and 27,000 tons of calcium cyanamide per annum ; at Conitza and Dugi-Kast, 60,000 to 80,000 tons of carbide per annum and an equal quantity of calcium cyanamide. The works are at present partially closed down, and one of them partially destroyed by fire (*Chem. Ztg.*, **1922**, 144/5 ; **1923**, 656 ; *Metallbörse*, **1923**, 545).

In the spring of 1919 the sub-Alpine districts of Savoy and the Dauphiné supplied about 230,000 h.p.; the larger valleys supplied 350,000 h.p., and the North Alpine district a total of 797,000 h.p. A number of centres of hydro-electric activity can easily be distinguished. Such centres exist, for example, on the Upper Arve and on the Bonnant, at the confluence of the Arly with the Doron, in the Middle Isère Valley, Combe de Savoie, Grésivaudan and the basin of the Breda, on the Romanche, in the valley of Maurienne and in the Tarentaise. The valley of the Arc is being developed with special intensity, the first installation in this valley having been erected in 1891–92. The development of the respective districts has been considerably stimulated. Not only are 100,000 workpeople now employed, but the population of communities which were formerly small has increased very considerably. In Villard-Bonnot there were 1,022 inhabitants in 1871 and 6,000 in 1919; the population of Livet increased from 924 to 3,000, that of Ugine from 2,325 (fifteen years ago) to 5,800. The character of the landscape between Séchilienne and Livet has been completely transformed by the erection of industrial installations. The power installations of the Tarantaise supply Lyons, those of Oisans supply St. Etienne and Roanne, and those of Gap supply Marseilles and the towns of the Côte d'Azur.[1] The development of the hydro-electric industry of the French Alps, which started in 1890 from quite small beginnings, is shown in the following table:—

Year.	Available h.p.
1910	470,000
1914	610,000
January, 1916	663,000
July, 1916	732,000
1918–19	1,045,000
1921–22 (anticipated)	1,500,000

On January 10th, 1919, a decree of the Minister of Public Works established a Commission to investigate the possibilities of power development in the whole of France. In Alsace the Rhine is supposed to be capable of supplying almost 1,000,000 h.p. between Basle and Lauterburg, and about 800,000 h.p. between the Swiss frontier and Markolsheim, near Strassburg.

The following large companies may be mentioned which operate in the Alpine departments, and which are in part active in connection with the nitrogen industry: the Société des Produits Chimiques d'Alais (et de la Carmague), formerly Société A. R. Pechiney et Cie.

[1] *Neue Zürcher Ztg.*, May 8th, 1919, from an article by Raould Blanchard in the *Revue de Paris.*

of Paris, with a capital of 80,000,000 fr. and 10 works; the Société Chimique des Usines de Rhone of Paris, with 3 works, and the Société d'Electro-Chimie, with a capital of 15,000,000 fr., founded in 1918. The Société hydrotechnique de France intends to establish a hydro-technical laboratory in the neighbourhood of Grenoble, which is later to be extended in order to form a research institute for the whole field of applied hydraulics; it is proposed to study in the first instance the power losses which occur in the various installations.

The enormous development of the electric industry in France is reproduced in the development of its nitrogen industry, which will be illustrated by figures below. The French Government has repeatedly assisted on a considerable scale; in 1915–16 alone £15,000,000 were spent to erect works producing cyanamide and nitric acid according to the process of the Nitrogen Products and Carbide Company (London). In 1918 an exhibition was held by the Société d'Encouragement pour l'Industrie nationale, and in 1920 a research institute was founded for the chemical industry of France.

Before the War two groups only worked continuously on a large scale on the fixation of atmospheric nitrogen—namely, the Société des Produits Azotés, at Notre-Dame de Briançon (Savoy), and the Nitrogéne Company at Roche de Rame on the Durance. The plant at Notre-Dame de Briançon (Tarantaise), on the Isère, produced 7,500 tons of calcium cyanamide by the Frank-Caro process in 1912–13. The Société des Produits Azotés also owns a works at Martigny in Switzerland (see Chap. VI.); its prices in the spring of 1921 were: 115 fr. per 100 kg. of granulated cyanamide, containing 19 to 21 per cent. of nitrogen, in metal drums; 75 fr. per 100 kg., powdered in sacks, containing 17 to 19 per cent. of nitrogen, and 90 fr. in metal drums. In 1920 the company raised their capital from 10,000,000 to 20,000,000 fr., and obtained the permission of the Spanish Government to erect a new works costing 1,500,000 fr. The works at Roche de Rame manufacture atmospheric nitric acid by the Pauling process.

Before the War the French industry interested itself especially in Serpek's aluminium nitride process. In 1909 the Internationale Nitridgesellschaft, Zürich, erected an experimental plant at Niedermorschweiler near Mülhausen, which was transferred to the newly formed Société Générale des Nitrures, of Paris, which also acquired the B.A.S.F. patents on silicon and titanium compounds. On December 31st, 1912, the Société Générale des Nitrures owned 283 French and other patents, and had applied for 87 further patents. Simultaneously large-scale experiments were undertaken at St. Jean de Maurienne in the valley of the Arc; the technical

difficulties which were encountered were reported on by the British Consul at Lyons, S. Vicor, in 1913.[1] The very high temperature of 1,500° to 1,600° C. necessary for nitrogenation affects the durability of the furnaces so seriously that so far no suitable constructional material has been found, and none of the proposed modifications have so far been successful. The works at St. Jean de Maurienne were intended to produce 1 ton of nitride per hour under industrial conditions. The electric furnaces consumed 2,500 kw. The installation was still under construction in 1913, and was so unsuccessful that by the middle of 1915 all manufacture of nitride was definitely abandoned. It was proposed at that time to obtain aluminium nitride from the Société Norvégienne des Nitrures (Norsk Nitrid A. S.), which utilised 10,000 h.p. in 1913–14 at Eydehaven, near Arendal. Although the Parisian parent company reported very favourably on the new Norwegian process in their report of 1914–15, these works also finally closed down. The plant at Eydehavn, near Arendal, was to have produced 40,000 tons of ammonium sulphate per annum by the Serpek method. In 1913 the Société Générale des Nitrures in Paris transferred their main patents to the Société d'Aluminium Francaise and to an American group in return for 8,000,000 fr. and an interest in the profits.[2] The interests above referred to intended to utilise the process for the production of aluminium. In America the American Nitrogen Corporation was formed for this purpose by the Aluminium Company of America, the Northern Aluminium Company of Canada and the Southern Aluminium Company. It is, however, doubtful whether the installation at Whitnay in North Carolina, which started manufacture in 1915 with 85,000 h.p., ultimately used the Serpek process, and the proposal of an English company to establish a works in British India, with a capital of £1,000,000, came to nothing. Nothing has been heard since 1915 of a process of Coutagne, resembling the Serpek process, which was tried in France. It has probably shared the fate which was prophesied by H. E. Fierz for the Serpek process (see Chapter VI.).

The first plant of all in which attempts were made to oxidise synthetic ammonia to nitric acid on a large scale was that at Vilvorde in Belgium erected by Duché in 1913, which utilised ammonia from Norwegian cyanamide. In 1913 the works were taken over by the newly formed Nitrogen Products and Carbide Co., Ltd., of London, which endeavoured during the War to improve the Ostwald process which was operated at Vilvorde in its original form. The new

[1] *Chem. Ind.*, 1913, pp. 713–714.
[2] O. Serpek, Ullmann's "Encyclopædia," vol. i., p. 294

Ostwald-Barton process was then operated at the English works at Dagenham (see below) to oxidise ammonia produced from cyanamide. The French Government entered into negotiations with the Nitrogen Products and Carbide Co., Ltd., of London, in 1915, and these resulted in September in the signing of an agreement, according to which the English firm was to erect similar plants in France. In the first instance £15,000,000 were supplied by the Government for this purpose. The first installation was erected at Angoulême for the Government explosive works. Part of this plant was working in September, 1916. Up to the close of 1918 £55,000 had already been paid to the Nitrogen Products Company in royalties, and minimum payments must be made for a further seven years, in spite of the fact that the production has greatly declined in the interval.

Cyanamide works were also erected at Sisteron and in the Tarn department, where 30,000 h.p. was to be supplied. Atmospheric nitric acid is produced at Laroquebrou, Cantal (power station on the Cère), at Bouvillard, near Aiquebelle, Savoy (power station of La Chambre on the Arc), and in Terette sur la Creuse, near Balesmes (Indre et Loire) by the Etablissements Poulenc Frères, and so forth. At Nanterre, outside Paris, there is a cyanamide works comprising 160 furnaces to produce about 100 tons of cyanamide or 16 tons of fixed nitrogen daily.

The industrial development of the Pyrenees has been considerable. It is quite recent, as in 1910 only 20,000 h.p. were utilised, whilst to-day this amount has increased to almost 150,000 kw., which is utilised in 20 electro-chemical or electro-metallurgical installations. The very rapid development of the last few years is the natural consequence of the War and of the dearth of coal. The oldest and most important carbide works is that of Anzat on the Viedessos River, which was erected in 1908 and was sold to the Société d'Alais, already referred to, in 1914. At the commencement of 1920 it was supplied with more than 20,000 h.p., which quantity is to be increased in the near future [1]; 4,000 tons of carbide are produced from limestone and coke or wood charcoal in 4 furnaces each utilising 800 to 1,000 kw. Carbide is also produced at the works of Castelet, on the Ariège (3,000 h.p.), and of Boussens on the Garonne. The manufacture of cyanamide was only started during the War, and it was partly converted into ammonium sulphate. Various large carbide and cyanamide works were only started in 1919–20, such as those of Lannemazan and Marignac. The works

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., pp. 119–120. From the *Mining Journal* of February 11th, 1920, through the *Journal du Four Electrique*. The original communication states that the data regarding the production of cyanamide must be accepted with reservation.

on the Lannemazan plateau are supplied with power from the Soulom power station of the Southern Railway Company. They were constructed during the War and have so far been mainly used for experimental purposes. The power station of these works also supplies the works at Eget belonging to the Southern Railway Company with 10,000 h.p., those of the Penarroya Company at Saint Lary with 20,000 h.p., and those at Loudenvielle (Government works) and Arreau (Government works) with 10,000 h.p. each. The Lannemazan plant contains twenty to thirty 2,000-kw. furnaces for the production of carbide. The cyanamide works operates on the Frank-Caro system, and has 300 nitrogenation units. Nitrogen is obtained by the Claude process of a purity of 99·8 to 99·9 per cent. The annual production of carbide is probably about 50,000 tons, corresponding to about 60,000 tons of cyanamide.

The Marignac Works of the Compagnie de l'Electricité Industrielle are still under construction. They will obtain their power from several power stations which are at present incomplete, among which there will be one on the Upper and one on the Lower Pique, each supplying 8,000 h.p. The remainder are in the vicinity of Luchon, and will obtain 25,000 h.p. from a fall 800 m. high, descending from the Oo Lake. They serve as central distributing stations for distributing the total current, which will be transformed from 70,000 volts to 150,000 volts. The Marignac plant is to contain six carbide furnaces each of 50 cu. m. capacity. The transformation of the carbide into calcium cyanamide will be carried out in a large continuous furnace of special construction, and the nitrogen will be produced as usual by the Claude process. The daily output of the works is to be 80 tons of carbide, 100 tons of cyanamide containing 22 per cent. of nitrogen, and 120 tons of cyanamide containing 15 per cent. of nitrogen. Wood charcoal will be used instead of coke in the carbide furnaces on account of the scarcity of the latter. According to the above figures the annual output, calculated as ordinary calcium cyanamide containing 20 per cent. of nitrogen, would be 60,000 to 65,000 tons. The Compagnie de l'Electricité Industrielle produces carbide in two furnaces in another works at Luchon, of which one is supplied with 800 kw. as two-phase current, and the other with 3,500 kw. as three-phase current.

The Société des Mines de Carmaux has erected a large power station to supply 20,000 kw. This power is used for operating 8 one-phase carbide furnaces, each of 2,000 kw., and 224 Frank-Caro nitrogenation furnaces to produce 46,000 tons of cyanamide per annum.

For some years ferro-alloys, electric steel, electric pig iron, silico-

manganese, abrasives, such as "boro-carbon," aluminium, chlorates, chlorine, caustic soda and other products have also been manufactured in the Pyrenees.

The Société Norvégienne de l'Azote et de forces hydroélectriques of Notodden (see Chapter IV.) acquired the rights to utilise the Soulom water powers in 1917 from the Southern Railway Company. They erected an atmospheric nitric acid works at Pierrefitte-Nestalas, employing the Birkeland-Eyde process as used at Notodden. The installation comprises 4 furnaces utilising 4,000 kw. each, and during the War concentrated nitric acid alone was manufactured for the production of explosives. The whole of the acid is now converted into calcium nitrate, excepting for a small quantity which is converted into sodium nitrate. In 1919 the Société Norvégienne transferred the works at Pierrefitte-Nestalas, of the value of about 12,000,000 fr., to the new Société Française de l'Azote, which intends to devote a capital of 40,000,000 to 50,000,000 fr. to the nitrogen fixation industry. It also transferred its concessions of water powers on the Gave de Gavarnie above Pierrefitte to the new company. It is intended to obtain 32,000 h.p. by the development of the water powers of Luz (Hautes Pyrenées) and Gèdre; for this purpose the Gaves (streams) of Héas, Estoubé, Garvanie and Aspe will be utilised, the latter having a fall of 270 m.; they are estimated to develop 16,870 h.p. When the power station at Luz on the Gave de Pau is finished, power will be received from there, and the power station at Soulom will then be available for other purposes. The Kuhlmann-Lambert-Rivière group (with about 10,000,000 fr.), the Compagnie nationale des Matières colorantes, and the Société des Produits de l'Azote, are said to be interested in the Société Française de l'Azote.

The "Chaudronneries des Pyrénées Soc. anon." was founded in 1920 with a capital of 4,000,000 fr., and is mainly devoted to the electric iron industry.

The Société l'Air Liquide, which increased its capital from 11,000,000 to 15,000,000 fr. in 1917, owns oxygen works in Paris, Le Havre, Nantes, Ponte-Sainte-Maxence, Audincourt, Lyons, Saint-Chamond, Marseilles, Rouen, St. Nazaire, Bordeaux, Nancy and Hénin-Liétard. In 1919 it was erecting two important installations for the production of hydrogen for airships from steam and iron. It also built electrolytic hydrogen plants for the arsenals at Cherbourg and Toulon. The company is represented abroad, by works at Vancouver, London and Sudbury, in Canada, at Ougrée in Belgium, and in Italy, Japan and the United States (by the Air Reduction Company). The full name of the company is l'Air Liquide,

Société Anonyme pour l'Etude et l'Exploitation des Procédés Georges Claude, Paris, and utilises the Claude process for the production of liquid air with expenditure of external energy, the liquid being fractionated. Apart from the Linde and Heylandt processes, which both produce liquid air with expenditure of internal work only, it is the most widely used process. M. v. Unruh gives the following figures at the end of 1919, which probably correspond approximately with the actual state of affairs :—[1]

Process.	Production in million cubic metres of oxygen gas at the end of 1919.
(1) Ges. für Lindes Eismaschinen A. G. Höllriegelskreuth, near Munich (productive capacity 72·5 million cu. m.)	45 to 50
(2) Heylandt Ges. für Apparatebau m.b.H. Berlin-Mariendorf . . .	14 to 15
(3) L'Air Liquide, of Paris . . .	3 to 4 (see Foreword)

L'Air Liquide became more closely identified with the nitrogen industry when G. Claude produced his process of direct synthesis of ammonia. It is similar to the Haber-Bosch process, though Claude proposes to use a pressure of 1,000 atmospheres and to obtain gases containing more than 40 per cent. of NH_3 instead of 13 per cent. at 200 atmospheres as hitherto. At a temperature of 500° to 700° C. 6 gm. of NH_3 are said to be obtained for each gram of catalyst compared with 0·5 gm. hitherto. It was already clear from Haber's work that an increase of pressure would result in more favourable yields of ammonia.[2] Claude's process will be more completely discussed later. Apart from numerous other publications,[3] Claude discusses the advantages of his method of working very completely in *Compt. rend.* **170,** 174–177 (1920),[4] and considers that it will result in considerable economy of energy. Ammonia from the high-pressure apparatus is separated as liquid without loss of pressure. Claude recommends the further utilisation of the ammonia by the Solvay process. He proposes to separate $NaHCO_3$ and NH_4Cl consecutively from the liquors by cooling to + 5° C., utilising for this purpose the heat of evaporation of the liquid ammonia from the Claude synthesis.[5] The proposal to use the ammonia soda process in conjunction with the nitrogen industry is not new ; thus the B.A.S.F. applied for a German patent for a similar method in 1915, and the Bayrische Stickstoff-Werke A.G. patented a similar process in 1916.[6] Claude

[1] F. Ullmann, "Encyclopædia," vol. **VIII.**, 1919, p. 637.

[2] *Zeitsch. f. angew. Chem.*, 1920, ii., 82 ; *Umschau*, 1920, p. 211.

[3] *Compt. rend.*, **169,** 649, 1039 (1919) ; *Chem. Zentralbl.*, 1920, ii., 431, 637–638. English pat. 130,086/1917, etc.

[4] *Chem. Zentralbl.*, 1920, ii., 524.

[5] *Chem. Ztg.*, 1919, p. 727 ; 1920, p. 152.

[6] *Ibid.*, 1920, p. 152.

maintains that he can work more satisfactorily and conveniently at pressures of 1,000 atmospheres than at 100 to 200 atmospheres. His process is said to have been successfully operated in the experimental plant at La Grande-Paroisse (see below), but the reports presumably refer merely to large-scale technical laboratory experiments, such as were communicated by d'Arsonval at the close of 1919 to the Académie des Sciences in Paris.[1] This communication was to the effect that very shortly Claude would be able to demonstrate a model which would produce 200 litres of liquid ammonia per day.

If one considers how difficult it was to convert the Haber-Bosch high-pressure synthesis into a workable process, it is readily understandable that in German expert circles the Claude process is regarded with considerable reservations. It is not at all clear that it is possible to work technically at 1,000 atmospheres more easily and cheaply than by the Haber process at 200 atmospheres, even by modifying the apparatus used in the latter.[2] [3]

In June, 1919, l'Air Liquide and the Compagnie de Saint-Gobain founded the Société Chimique de la Grande-Paroisse, the initial capital of which was 20,000,000 fr., which was increased in 1920 to 34,000,000 fr., in order to exploit G. Claude's process of manufacturing ammonia. For this purpose l'Air Liquide placed at the disposal of the new company the works at Grande Paroisse, near Montereau, which were utilised during the War for the manufacture of liquid chlorine. The additional capital of 14,000,000 fr. is to be utilised to further develop the manufactures hitherto pursued, more particularly the liquefaction of air and so forth, and also the production of ammonia by Claude's process, after experiments lasting over a considerable time had been carried out, the results of which were favourable. Licences to use the Claude process were acquired for Great Britain, South Africa, India, Australia and New Zealand by Cumberland Coal, Power and Chemicals, Ltd., in the spring of 1920 in order in the first instance to erect a works in Cumberland. The first technical unit to employ the Claude process in the experimental works at La Grande-Paroisse is said to be working satisfactorily.

In spite of these promising indications, latter events seem to indicate that the Claude process is not fully able to compete with the Haber-Bosch process. Negotiations between the French Government and the B.A.S.F. concerning the erection of an ammonia works utilising the Haber-Bosch process, which had been

[1] *Chem. Ztg.*, 1920, p. 152.

[2] *Zeitsch. f. angew. Chem.*, 1920, ii., p. 111; *Chem. Ind.*, 1920, p. 236.

[3] Supplementary details regarding "l'Air Liquide" and the Claude process will be found in the Foreword.

carried out for a considerable period, terminated in the signing of an agreement on November 11th, 1919.[1] The French Haber plant is to be erected by partially utilising the explosive works near Toulouse [2]; the Government is entrusting the operation of the process to a private company, the Etablissements Kuhlmann. The fact is remarkable that the German process was chosen instead of the French process, for although the acquisition of licences for the former process was ensured and facilitated by the stipulations of the Versailles Peace Treaty, the French Government was able to choose freely, having already negotiated with the Claude group. The Cie. Nationale de l'Azote, with 12,500,000 fr. capital, was founded for the exploitation of the Haber process; the Mines de Béthune, the Compagnie Nationale des Matières Colorantes, the Etablissements Kuhlmann, the Société des Produits Azotés and others are represented in this concern. Interest is also being shown in France in the modern development of the German calcium cyanamide industry, so that co-operation of works in both countries may possibly be expected.[3] The partial utilisation of Claude's process in conjunction with the other is foreshadowed in Toulouse.[4] [4a]

Two companies affiliated with l'Air Liquide, namely, the Société Algérienne and Société Tunisienne de Gaz Comprimés, combined in 1919 to form the Société Nord-Africaine de Gaz Comprimés. The capital of the new company, which is interested in the Soc. Marocaine de Gaz Comprimés, is 1·4 million fr. The co-operation of l'Air Liquide with Stearineries et Savonneries Lyonnaises, which was reported early in 1920, is doubtless connected with the interest of l'Air Liquide in the manufacture of hydrogen.[5]

The Société Industrielle de Chimie d'Extrême-Orient of Paris and the Société Centrale des Industries de l'Air Liquide et de l'Azote, which was founded in 1920, and increased its capital to 20,000,000 fr. in 1920, are working in the same field as l'Air Liquide.

A movement has arisen in France, at the head of which is Camille Matignon, Professor at the Collège de France, which endeavours to show that the leading idea of the Haber process is not of German origin. C. Matignon has repeatedly endeavoured, both verbally and in writing, to prove the correctness of his views, without having been able to confirm them satisfactorily.[6] He first mentions Le Chatelier's

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 276.
[2] *Chem. Ztg.*, 1920, p. 564.
[3] *Metallborse*, 1920, p. 1198.
[4] *Zeitsch. f. angew. Chem.*, 1920, ii., 294.
[4a] See Foreword.
[5] *Zeitsch. f. angew. Chem.*, 1920, ii., 239.
[6] Lectures on March 19th, 1916 und March, 1918; Hesse-Grossmann, "Englands Handelskrieg und die Chemische industrie," vol. iii. (Stuttgart, 1919), pp. 47–74; *Chem. Ztg.*, 1918, p. 412; also *Zeitsch. f. angew. Chem.*, 1918, iii., 282, 358.

French Patent 313,950 of 1901, which deals with experiments with compressed mixtures of nitrogen and hydrogen, which united with violent explosion, air having gained access to the gaseous mixture. At the Twenty-fourth General Meeting of the German Bunsengesellschaft at Berlin, in 1918, C. Bosch pointedly criticised Le Chatelier's alleged priority.[1] Matignon and Haller then called attention to British Patent 1,833 of the year 1865, in which Dufresne applies in the name of Charles Tellier for a process in which ammonia is produced as a by-product in the production of oxygen by the direct combination of hydrogen and nitrogen with the assistance of spongy iron. According to the French patent of Tessié du Motay, No. 92,346 of 1871, ammonia is obtained by alternately passing hydrogen and nitrogen over heated titanian nitride or, according to French Patent 138,472 of 1881, over finely divided iron. In the corresponding German Patent 17,070 of 1881, which is taken out in the name of a firm founded by Tellier, reference is made to the influence of pressure (10 atmospheres). According to French Patent 255,183 of 1896, by the La Christiania Mine Company, nitrogen and hydrogen are passed through a heated chamber containing a titanium catalyst. Matignon and Haller also refer to the work of Ramsay and Young (1884) and of Halvati in 1895, in order to support their contention, which centres on the question whether the Haber patents may be considered as valid.

Apart from other considerations, it should be clear, even to the opponents of the Haber-Bosch process, that it would hardly be possible to carry on the works at Oppau and Leuna with the help of any of the patents above referred to, and that this fact alone indicates the achievement of a new technical effect by the Haber-Bosch process to which paragraphs 1 and 2 of the German Patent Law of April 7th, 1891, can be applied.

In 1919 the Société d'Etudes de l'Azote was founded in Paris with a capital of 1,500,000 fr., in order to acquire patents, concessions and processes bearing on the atmospheric nitrogen industry. The new company is particularly concerned with the utilisation of rights arising out of the Versailles Peace Treaty, for example, the Haber process. The practical exploitation of any patents, and so forth, which may be acquired, will be transferred from the company to operating companies. The company unites the interests of the following firms: Société de Saint-Gobain, Produits Chimiques d'Alais, l'Air Liquide, Soc. Générale des Nitrures, Usines du Rhône, Le Creusot, Compagnie Nationale de Matières Colorantes, Etablissements Kuhlmann, Soc. Gillet et fils de Lyon, Soc. des Produits

[1] *Zeitsch. f. angew. Chem.*, 1918, ii., 242.

Azotés, Soc. des Mines de Lens, Soc. d'Electrochimie, and Soc. des Mines de Béthune, which are thus combined into a syndicate dealing with nitrogen fixation. From the commencement the company has mainly concerned itself with the Haber-Bosch process. The conclusion of the agreement between the French Government and the B.A.S.F., which was supported by the introduction of a law by the Minister for War, approved by the Chamber, may be considered to be due to the initiative of this company.

The by-product coking industry has not developed nearly so rapidly in France as in other industrial countries. The production of ammonium sulphate, in tons, in 1900 and 1910 was :—

	Germany.	Great Britain.	United States.	France.	World Production.
1900 . .	120,000	213,000	58,000	37,000	496,000
1910 . .	373,000	369,000	116,000	56,000	1,057,000
Ratio of increase.	1 : 3·1	1 : 1·73	1 : 2·0	1 : 1·5	1 : 2·13

The War, which more particularly affected the industrially important departments of the north and east, had a devastating effect. The ammonium sulphate production (in tons) was as follows :—

	1913.	1917.	Percentage Diminution.
From gas works	22,000	19,200	12·8
From effluents, sewage, etc. .	12,000	5,500	54·1
From coke ovens	38,500	9,300	77·8
From various sources . .	3,500		
Totals	76,000	34,000	55·3

The extraordinary value of by-product recovery was only recognised in France at a relatively late date ; only for this reason was it possible that large iron and steel works, such as those of Creusot, should use raw coal, which had not previously been coked, in their blast furnaces. We learn from a report which L. Tissier presented to the French Chamber on February 19th, 1918, in reference to the Bill for the establishment of a central control of chemical fertilisers,[1]

[1] See Hesse-Grossmann, "Englands Handelskrieg und die Chemische Industrie" (Stuttgart, 1919), pp. 37-46.

that these circumstances had improved little, if at all, in the interval. It may be considered as an accidental circumstance that raw French coal is at all suitable for use in blast furnaces, as this is not the case with every kind of coal, but, on the contrary, a particularly resistant quality is required which is not crushed under the weight of the charge. A blast furnace of average size produces 100 tons of pig iron per twenty-four hours, and requires for this purpose 150 tons of coal; this would give on the average during the previous coking 150 × 10 = 1,500 kg. of ammonium sulphate. As the French production of iron in 1913 was 5·1 million tons (69·3 per cent. from the east, 17·1 per cent. from the north), and as one may assume, from what we have already mentioned, that a considerable proportion of the blast furnaces work without previous coking of the coal, the total loss of ammonium sulphate is certainly very considerable. In 1919 the pig iron production of France was 2·412 million tons, of which 1·112 million tons, or 46·1 per cent., was from Alsace-Lorraine (which produced 4,000,000 tons before the War), and 469,954 tons, or 19·4 per cent., came from Eastern France. The French production of iron ore was 13,871,137 tons in 1920 and 9,429,789 tons in 1919. The unsatisfactory position of the coke industry, and the fact that the larger proportion of the producing works lay in the occupied territory, explains how it is that the atmospheric nitrogen industry was able to develop with such astonishing speed in France by utilising the wealth of available water power.

The backward condition of the French coke-oven industry has recently been recognised by the experts; Professor Berthelot came to the conclusion, in a lecture to the Société de Chimie Industrielle,[1] that the Americans are very much more advanced in this respect. By suitably increasing the dimensions of the ovens and lining them with silica bricks, they have been able in America to increase the output to 20 tons of coal per oven daily compared with 6 to 8 tons in France. The constructional costs are as 8 in America to 9 in France, and the cost for labour, up-keep and so forth as 2 to 3. The credit for the superior American results is primarily due to the Koppers Company, which is the American branch of the German firm of H. Koppers, of Essen-on-Ruhr. According to a report of the last-named firm,[2] 72 per cent. of American by-product coking ovens are at present of the Koppers type. The French ovens need much gas for heating, while German ovens only require 137 kg. of coke for this purpose per ton of the coal which is coked; the costs for upkeep, wages and power are relatively very low in the case of the latter. In England

[1] *Metallbörse*, 1920, p. 1160.
[2] *Mitteilungshefte*, 1919, No. 9.

the beehive ovens are being methodically replaced by modern coke ovens. The question of the most suitable fire-brick and of methods of prevention of corrosion of the oven walls by coal containing sodium chloride have been successfully dealt with in that country by Hancock and others. At the close of the lecture, Berthelot refers to a new coking process by Charpy, Godchot and Decorps, by means of which otherwise unsuitable coal is to be coked in two stages.

France consumes 12,000,000 tons of coke per year and produces 2,000,000 tons. This heavy deficit will undoubtedly lead to endeavours to increase the output of the French coking industry within the next few years; far larger quantities of ammonium sulphate may therefore be relied on from this source. In 1920 a company was founded in Paris with a capital of 7,000,000 fr., named the Fours à Coke et Installations Métallurgiques.

The large firm Etablissements Kuhlmann restarted their plants in Belgium and in the North of France, for example at Loos-les-Lille, Roubaix, Rieme, near Ghent, etc., in May, 1920, and increased their capital at that time from 60,000,000 to 100,000,000 fr. The firm owns nine chemical works which manufacture sulphuric acid, sulphates, such as ammonium sulphate, chlorine and sodium compounds, such as eau-de-Javelle, and also superphosphates. The capital increase of 40,000,000 fr. is to be used for new construction, repairs, and so forth. The Etablissements Kuhlmann, the founder of which discovered the method of catalytic combustion of ammonia with a platinum contact (see above), is the property of the Société d'Etudes de l'Azote, already referred to, and recently acquired from the Government the explosive works at Toulouse, in which it is proposed to operate the Haber-Bosch process.

The peat bogs of France, many of which are very important, have not as yet been much exploited industrially, although attention has recently been directed to them.[1] In Châteauneuf, in Brittany, the water contents of peat are reduced by pressure from 90 to 60 per cent., and superheated steam is then blown over it for 25 minutes at 160° C., according to an improved Ekenberg process. After re-pressing the peat is dried and is sold as a fuel under the name of "turbon."

France is one of the few countries in which considerable quantities of ammonium sulphate are obtained from fæces and by gasification of the sludge from the purification of effluent waters. The quantities of ammonium sulphate obtained in this way amounted to 13,000 tons in 1905 (of which 10,000 tons came from Paris), 12,000 tons in 1913,

[1] C. Galaine and C. Houlbert in the Académie des Sciences, May 18th, 1918; *Chem. Ztg.*, 1918, p. 453.

and 5,500 tons in 1917. In 1912 France utilised the following quantities of fertilisers :—

	Tons.
Superphosphate	1,941,000
Basic slag	679,000
Chile nitrate	300,000
Synthetic nitrogen compounds	2,400
Calcium cyanamide	50,000
Ammonium sulphate	90,000
Total consumption of nitrogen	69,308
Potassium sulphate	16,000
Potassium chloride	45,000
Total consumption of potash	44,120

In the year 1917–18 the following quantities were supplied for agricultural purposes :—

	Tons.
Superphosphate	450,000
Basic slag	80,000
Chile nitrate	56,000
Ammonium sulphate	34,000
Total nitrogen	16,435
Potassium chloride	15,000
Total potash	11,275

L. Tissier estimates that in 1917–18 the land available for cultivation in France was reduced by 2·4 per cent., that is, by about 51·96 million hectares, due to the circumstance that a considerable portion of France could not be effectively cultivated during War conditions. Allowing for this circumstance, there was a deficit in the supply of fertilisers of 76·8 per cent. of superphosphate, 88·2 per cent. of basic slag, 76·4 per cent. of nitrogen, and 74·3 per cent. of potash, compared with the supplies in 1912. In 1917–18 the main quantity of the synthetic nitrogen compounds was being used for the production of munitions.

In 1918–19 21,250 tons of nitrogen and 1·05 million tons of phosphatic fertilisers were available for agriculture. Apart from the Alsatian potash mines, the salt beds in the South of Tunis, covering 20,000 hectares, should supply 30,000 to 35,000 tons of fertiliser annually, containing 30 to 45 per cent. of potassium chloride. In the spring of 1917 only about 180,000 tons of superphosphate could be produced, as the greater part of the sulphuric acid was required for the production of munitions. At that time the Ministry of Munitions only liberated 10 per cent. of the production of acid for the purpose of superphosphate manufacture. At a later period sodium bisulphate was utilised instead of sulphuric acid ; 500,000 tons of sodium bisulphate per annum were produced as a by-product by the

munitions works at 1 fr. per ton. In spite of the protests of the superphosphate works, the request of the Ministry of Agriculture for support for this new industry was not acceded to. In accordance with an order of the War Ministry, the explosive works at Angoulême and Toulouse erected experimental plant for an output of 1,200 tons per month, in order to persuade industry and agriculture of the utility of the new method. Superphosphate manufactured in this manner contains only 7 to 8 per cent. of phosphoric acid. The French sulphuric acids works, which had an output of about 1,000,000 tons, calculated as 100 per cent. acid, in 1913, are now able to supply 2,000,000 tons. On the initiative of the Under-Secretary of State for Artillery and Munitions in November, 1915, a union of sulphuric acid manufacturers was formed, the Union des Fabricants d'Acide Sulfurique de France, which included almost all the producers with the exception of the Compagnie de Saint-Gobain. The latter company was founded in 1915 on the initiative of the Munitions Ministry, in order to exploit the pyrites deposits of Saint-Gobain. In spite of increased production, amounting to 90,000 tons per month in 1916, this was still insufficient, so that the Union erected a number of new sulphuric acid works on behalf of the Government, which supplied 100,000 tons per month at the commencement of 1918. In the Department of the Bouches-de-Rhône alone sufficient sulphuric acid can now be produced to supply the peace requirements of France. The production of explosives increased from about 15 tons per day in 1913-14 to 1,000 tons at the end of 1916. In January 1915 the output was 150 tons per day, and in the spring of 1916 750 tons per day.

The annual production of nitric acid in 1913–14 was about 15,000 tons. During the War so many Valentiner nitric acid plants were erected that in 1918 30,000 to 50,000 tons could be produced per month. This enormous increase explains without difficulty the enormous quantity of bisulphate obtained as a by-product according to the equation :—

$$NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3.$$

The values of the nitric acid imports into France were :—

	Fr.
1913 (332,115 tons) . .	8,295,000
1914 (297,190 tons) . .	—
1915	876,333,000
1916	405,525,000
1917	408,298,000
1918	221,147,000

In 1918 the French Government made every endeavour to increase the imports of nitrate. Thus they allowed French vessels carrying Chile nitrate to return with articles the export of which was otherwise forbidden. Even during the first period of the War there was for a time a tax on the storage of Chile nitrate. This tax amounted to 3·60 fr. per 100 kg. gross weight in 1920, when it was re-introduced, but no direct tax is to be levied on Chile nitrate imports.

The following table contains the figures for the national output capacity of French industry in 1913–19. Naturally these figures were far from being attained in practice; instead of 3,000,000 tons of 100 per cent. sulphuric acid, 2,000,000 tons only were actually produced, and only 100,000 tons of cyanamide instead of the maximum output capacity of 300,000 tons. The output capacities in tons were:—[1]

	1913		1919	
	Output Capacity.	Consumption.	Output Capacity.	Consumption.
Sulphuric acid, 58° Bé. .	1,160,000	1,172 500	2,500,000	1,500,000
Sulphuric acid, 66° Be. .	58,000	58,000	1,200,000	—
Fuming sulphuric acid .	6,000	6,000	300,000	25,000
Nitric acid . . .	2,000	185,000	360,000	20,000
Sodium salts . .	625,000	506,000	800,000	650,000
Liquid chlorine . .	300	—	—	—
Calcium carbide . .	32,000	28,000	200,000	—
Calcium cyanamide .	7,500	8,000	300,000	—
Ammonium salts . .	75,000	95,000	200,000	150,000
Nitrate	—	9,500	250,000	520,000
Natural phosphates .	2,700,000	1,220,000	3,000,000	2,700,000
Superphosphates . .	1,965,000	1,900,000	2,500,000	2,500,000
Phosphorus . . .	300	30	3,600	—

Broadly speaking the above table is of limited value only. The nitric acid production for 1913 is given elsewhere as 15,000 tons, which is a more accurate figure.[2] The actual production of calcium carbide in 1918 was about 120,000 tons.[3] The new works, with an output capacity of 150,000 to 180,000 tons, only started partial production after the conclusion of the Armistice, so that an actual production of 200,000 tons for 1919 is probably in accordance with

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 178.
[2] *Ibid.*, 1919, ii., 502; *Chem. Ztg.*, 1919, p. 679
[3] *Umschau*, 1920, p. 75.

the facts. As has already been mentioned, only about 100,000 tons of cyanamide were produced in 1919. The figures for ammonium salts in 1919 show the influence of the synthetic production, if one allows for the decline of the coking industry, as approximately 125,000 to 150,000 tons out of the total production of 200,000 tons may be ascribed to the synthetic products (ammonium sulphate and ammonium nitrate). On the assumption that of the consumption of nitrate, which was 520,000 tons in 1919, 300,000 tons were used for agricultural purposes, as in 1912, and that the remaining 220,000 tons were converted into the theoretical quantity of 148,000 tons of 100 per cent. nitric acid, there remains in 1919 an excess of 212,000 tons which must have been obtained synthetically, but this figure is obviously much too high. Naturally such calculations rest on very uncertain foundations, and can only lead to approximate figures; thus the heading "nitric acid" contains no reference to the strength of the product, which we have therefore here assumed to be 100 per cent.; in spite of these difficulties, however, the figures give some indication of the actual achievement of the French nitrogen industry, which developed to an extraordinary extent during the War. The proportional increase of the cyanamide industry during the interval 1913–19 is actually greater than in Germany, if we consider either the maximum output figures or the actual production.

If one considers all the more or less reliable figures, the maximum annual output capacity of the French nitrogen industry will probably be approximately as follows:—

	Tons.
Atmospheric nitric acid and nitric acid produced by oxidation of ammonia	50,000
Cyanamide	300,000
Synthetic ammonium salts from cyanamide	125,000
Ammonium salts from coke ovens	75,000
Saltpetre and other nitrates (ammonium nitrate, calcium nitrate)	100,000

It should be observed, however, that in these statistics various products appear more than once, for example, ammonium nitrate and ammonium salts from calcium cyanamide, and that the quantities given could not necessarily all be produced simultaneously, but are dependent on one another. Thus if the manufacture of calcium or ammonium nitrate increased that of free nitric acid would be correspondingly decreased.

The French exports and imports of the products which interest us here in 1917 and 1919 were as follows, expressed in tons:—[1]

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 261.

	Exports.			Imports.		
	1917	1918	1919	1917	1918	1919
Nitric acid	10·0	140·24	489·3	—	31·7	39·7
Ammonia	67·8	418·4	84·6	361·6	1,551 3	928·7
Ammonium sulphate (crude).	83·3	893·7	202·8	7,325·4	13,599·0	20,708·6
Ammonium sulphate (refined)	257·8	2,508·9	142·6	18·9	255·2	1,348·8
Other ammonium salts (crude)	33·0	2,788·2	33·8	51,256·7	66,631·5	6,501·0
Calcium nitrate and calcium cyanamide . . .	—	6,395·1	11·0	8,592·0	9,233·2	6,389·2
Potassium nitrate . .	20·0	99·4	46·2	2,182·6	2,641·2	2,789·4
Chile nitrate . . .	—	—	—	249,299·5	453,664·2	118,254·6
Sodium nitrate from other countries . . .	—	—	—	7,342·5	0·4	37,914·0
Sodium nitrate total . .	439·7	7,228·4	538·0	256,572·0	453,664·6	156,168·6
Calcium carbide . . .	1,633·0	764·3	1,885·2	33,093·8	25,181·3	15,970·3

The prices of the more important nitrogenous fertilisers per 100 kg. were :—

		Fr.
Calcium cyanamide, 17 to 18 per cent. N.	December, 1919 . .	70
	January, 1920 . .	70
	March, 1920 . .	92
Calcium nitrate, 13 per cent. N, net in barrels, Rouen.	December, 1919 . .	75
	January, 1920 . .	75
	March, 1920 .	82
	May, 1920 . . .	104
Sodium nitrate (Dunkirk), 15 to 16 per cent. N.	December, 1919 . .	106
	January, 1920 . .	120
	March, 1920 . .	124
	May, 1920 . . .	140
Ammonium sulphate, 20 to 21 per cent. N, f.o.r. Paris.	December, 1919 . .	155
	January, 1920 .	155
	March, 1920 .	160 165
	May, 1920 . . .	175
(Commencement of 1919 : 96 fr.)		
Ammonium nitrate, 33 to 34 per cent. N.	March, 1920 . .	150
(Commencement of 1919 : 145 fr. ; earlier, 318 fr.)		

On August 8th, 1919, detailed negotiations were carried on at Versailles regarding the deliveries of ammonium sulphate according to the Peace Treaty of Versailles. Thus for April, 1920, the price of German ammonium sulphate f.o.r. at French frontier stations was 155 fr. (see also Chapter III.).

The Société d'Eclairage, Chauffage et Force motrice par le Gaz, of Gennevilliers, commenced during the War to roast spent oxide with about 50 per cent. of iron pyrites in Herreshoff ovens in order to obtain the acid necessary for fixing their ammonia.

The French atmospheric nitrogen industry certainly played

and more than 24 per cent. of this total, namely, 2,219,868,000 tons, was exported. The production of coke in millions of tons was :—

1905	17·732
1910	19·642
1913	18·645
1915	20·059
1917	21·995
1918	21·066

In 1918 38·220 million tons of coal were converted into coke. The coke so produced had a value of £35,414,000. Since 1899 a decrease in the amount produced per man employed in the pit has become noticeable, having dropped from 310 tons in 1899 to about 230 tons in 1919.[1]

Increased attention has been directed to economy in fuel and in the utilisation of thermal energy. By centralising the production of power and utilising all the by-products, it is hoped that £100,000,000 can be saved annually in England, and that by this means the taxation difficulty may be diminished. The number of electric power stations in 1918 is given as 600. A committee of the British Board of Trade [2] proposes to replace the smaller, uneconomical, power stations by 16 large power stations. These are to be situated on important waterways. In this way it is estimated that 55,000,000 tons of coal would be saved annually. The water powers of Scotland and North-West Ireland are to be included in this programme. So far they have only been utilised on a small scale for the production of aluminium. A subsequent plan of the British Government provides for a similar unification of electric supply from 12 power stations [3] for a provisional period. All industrial works will be forced to draw their supplies from these central power stations. A portion of the munitions works are building motors of standard design and other requirements for this electrification scheme. The supervision of this work has been entrusted to the Coal and Power Group of the Reconstruction Commission, which is divided into two sub-divisions for the preservation of coal supplies and for the supply of electric power.

At the close of the War the British output per year was about 100,000 tons of nitric acid and sulphur-trioxide, 60,000 tons of trinitrotoluene, and 35,000 tons of cordite (produced from guncotton and nitro-glycerin). The manufacturing costs per ton were about £185 for picric acid, £50 for ammonium nitrate, and about £100 for

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 21.
[2] *Ibid.*, 1918, iii., 363.
[3] *Ibid.*, 1918, iii., 453.

trinitrotoluene. From the first, therefore, efforts were made to replace picric acid by ammonium nitrate. At an early date the Research Department at Woolwich introduced a mixture of 80 parts of ammonium nitrate and 20 parts of trinitrotoluene. This mixture, which is known as "amatol," is 5 per cent. more effective than other high explosives, such as those containing picric acid, but possesses less brisance, and is more difficult to detonate. The manufacturing costs, amounting to £60 to £65 per ton, were naturally considerably less than those of picric acid. Amatol was, finally, so much improved in quality that it was used on a large scale as a substitute for picric acid for filling shells. The manufacture of picric acid in England ceased entirely in the summer of 1918.[1]

The choice of amatol as the normal shell filling necessitated the production of about 3,000 tons of ammonium nitrate per week. Ammonium nitrate thus became the main product of the British nitrogen industry. At first the oxidation of ammonia to nitric acid was not considered; at a later date, when the supply from Chile became difficult, the works at Dagenham were started. At the same time ammonia oxidation plants were erected at a number of gas-works in order to produce ammonium nitrate directly. Initially, and for a considerable time, ammonium nitrate was mainly produced by Brunner Mond & Co., Ltd., and elsewhere, by one of the following processes:—

(1) $2NaNO_3 + CaCl_2 = 2NaCl + Ca(NO_3)_2$

$Ca(NO_3)_2 + (NH_4)_2SO_4 = CaSO_4 + 2NH_4NO_3$

(2) $NaNO_3 + NH_3 + CO_2 + H_2O = NaHCO_3 + NH_4NO_3$.

(3) $(NH_4)_2SO_4 + 2NaNO_3 = Na_2SO_4 + 2NH_4NO_3$.

The sulphuric acid production of the British Empire increased from about 1,000,000 tons before the War to 1·75 million tons in 1918–19. Articles in the *J. Soc. Chem. Ind.* established the fact that the highly important synthesis of ammonia from the elements had hitherto appeared as an established industry in Germany only, and that the work achieved in Germany, resulting in the practical application of the Haber-Bosch method, "represents an extraordinary achievement if one considers the complication of the plant and remembers that manufacture by the process was only started in 1913." The same article [2] also mentions that there were doubts whether the cyanamide industry, which had been established in all countries taking part in the War, would be able to compete under normal conditions.[3]

[1] *Zeitsch. f. angew. Chem.*, 1919, i., 297, ii., 813.
[2] *Ibid.*, 1920, ii., 60.
[3] *Chem. Ind.*, 1915, p. 331.

In 1916–17 the Association of British Chemical Manufacturers was formed to unite the whole chemical and allied industries of Great Britain. Special Government Commissions serve or served to organise the fertiliser, acetylene, oil shale and ammonium sulphate industries. In spite of these organisations, the Royal Agricultural Society had frequently occasion to point out [1] that it would be impossible to achieve a larger agricultural production in England whilst supplies of sulphuric for superphosphate manufacture, and of nitrate and ammonium sulphate were so deficient. After the War conditions naturally changed fundamentally.

In contrast to the stagnation in other countries, British capital showed more enterprise in 1919 than in 1918. Thus the amounts of newly-issued capital were :—

	1918 £	1919 £
In the nitrate industry . .	192,505	172,150
In commercial and industrial undertakings . . .	10,337,139	90,091,207

English fears of competition from the German ammonia industry [2] caused attention to be directed to the energetic study of the Haber-Bosch process.

In 1916 the British Patent Office granted a licence for the utilisation of three patents of the B.A.S.F., on the production of synthetic ammonia, to Gas Developments, Ltd., of Walsall. This firm had, however, so many misgivings, that they proposed to pay a small royalty only, or no royalty at all, to the owners of the patent, as in consequence of the fact that the description was neither very clear nor very detailed, elaborate researches would be necessary before the process could be practically utilised. The Patent Office finally decided on 5 per cent. of the sale price, whereas Gas Developments, Ltd., had only offered 2½ per cent. At an earlier date the Mersey Chemical Works, Ltd., of London, had acquired certain of the B.A.S.F. patents for £215 and 50 per cent. of the profits, but had not been able to use them. In 1916 Gas Developments, Ltd., had already spent £1,500 in experiments. At that date they announced that they had been successful, and would be able to produce 40 tons of ammonia per week henceforth. E. B. Maxted, a director of the company, estimated the cost of plant at £25,000. At a later date he communicated details of the method of working.[3] Nitrogen is obtained from air by Pictet's process, from a plant with a capacity of 400 cu. m. per

[1] *Chem. Ztg.*, 1917, p. 322.
[2] *Chem. Ind.*, 1915, p. 479.
[3] *J. Soc. Chem. Ind.*, 36, 777 (1917).

hour. Hydrogen is obtained from water-gas by the steam-iron process. Maxted gives no details about the iron catalyst to which traces of another substance are added. The ammonia which is produced is mixed with air in the proportion of 1 to 10 (or with pure oxygen from the fractionation of liquid air) and burnt at 700° C. over a contact material which is not platinum. Comparative figures are given, which are intended to show the utility of the method by comparing it with the production of nitric acid directly from the air, and with the production of cyanamide. The Research Department of the Ministry of Munitions has also protected details of a modified Haber process by 12 patents which were taken out in the names of members of its staff.

In spite of these efforts the work does not appear to have been crowned with success up to date, for by the middle of 1917 attempts were made everywhere in England to spread the erroneous information that the Haber process was commercially quite unprofitable, as the expenses and the risk were far too high, and that the process was only definitely established in Germany owing to the necessities of the War period. A new method was advocated in place of the Haber-Bosch process, namely, that of the International Nitrogen and Power Company, of London, which was said to be extraordinarily cheap and to render England independent of imports of Chile nitrate. This process was said to have been worked in Manchester ten to twelve years previously, and it was also said that Manchester capitalists associated with the bleaching industry intended to erect a works. The scheme failed, as the furnaces and apparatus could not withstand the necessary temperature of about 2,000° C.[1] It was said, however, that these difficulties had meanwhile been overcome in a French works, which had been producing for some time. It may probably be assumed that this secret process consists of a modification of an electric furnace for the preparation of atmospheric nitric acid. Further details have not been published, but it has transpired that a works in Manchester manufactures atmospheric nitric acid utilising 15,000 h.p.[2] and the above-mentioned new enterprise was also to have been established in Manchester.

A representative of the Ministry of Munitions stated in the House of Commons on May 2nd, 1918, that extensive experiments had been carried out in England since July, 1916, with the object of imitating the Haber-Bosch process, but that it had only been possible in the last few months to transfer these from the laboratory stage to a practical experimental plant. In 1919 the *Westminster Gazette*

[1] *Chem. Ztg.*, 1917, p. 888.
[2] *Zeitsch. f. angew. Chem.*, 1918, iii., 152.

reported that the attempt to fix nitrogen in this way had been abandoned after the expenditure of £1,000,000 by the Government. The paper asked for explanations[1] particularly in view of the fact that in Germany the problem had been solved with complete success, and was of equal importance for military and agricultural purposes.

On October 7th, 1919, Brunner Mond & Co., Ltd., applied for the grant of licences to utilise the following 10 English patents of the B.A.S.F. : 17,642/09, 17,951/09, 14,023/10, 19,249/10, 19,778/10, 5,833/11, 5,835/11, 21,151/11, 28,167/11 and 44,509/10. Nine of these patents deal with the manufacture of ammonia and one with the purification of oxygen.[2] These attempts have also been unsuccessful so far, as is clear from the article in the *J. Soc. Chem. Ind.*, already referred to, which emphasises the fact that ammonia synthesis has been established as a stable industry in Germany only (1920).

A number of reconstruction committees were formed more particularly in 1918. The Nitrogen Products Committee, which was formed in June, 1916, is of special interest to us. The object of this committee was the critical investigation of the various processes connected with the fixation of nitrogen and a decision on their relative importance for England under war and peace conditions ; finally it was entrusted with the initiation of experiments on the various processes. The committee furnished its first provisional report in 1917[3] ; Sir William Crookes, who was the first to point out the importance of the nitrogen problem to the civilised population of the world, took part in its sittings.[4] In its final report, dated January, 1920,[5] the Nitrogen Products Committee advocate the immediate adoption of the manufacture of cyanamide (60,000 tons annually), and also the immediate erection of a Haber-Bosch installation for an annual production of 10,000 tons of ammonia. It was intended that both works should primarily serve for purposes of national defence. An annual production of 60,000 tons of cyanamide corresponds to about one-eighth of the ammonium sulphate production. The committee recommend that the cyanamide plant should either be carried on as a private undertaking, if necessary with Government support, or as a direct Government enterprise. If the necessary electric power were supplied by Scottish water power, then the total outlay for plant would be about £1,680,000 ; a steam

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 625.

[2] *Ibid.*, 1919, ii., 787.

[3] *J. Soc. Chem. Ind.*, 1917, p. 1196.

[4] See Hesse-Grossmann, Ullmann's "Encyclopædia," vol. III., pp. 99 *et seq.* ; *Chem. Trade Journal*, i., 12, 1917.

[5] *Engineering*, **110**, 218 (1920) ; *Neue Zurcher Ztg.*, July 15th, 1920 ; *Chem. Ind.*, *1918, p. 1653 ; 1920, p. 261*,

power station would alone cost £800,000. The capital cost of the Haber-Bosch installation is estimated at £600,000, or at £780,000 if the conversion into ammonium sulphate is included. In the opinion of the Committee it would be advantageous to utilise for the purpose the works at Billingham-on-Tees[1] which was still in a quite unfinished condition. They recommend that the ammonia oxidation process should be utilised to an extent which would suffice for a production of 10,000 tons of concentrated nitric acid per annum or the corresponding amount of nitrate. £120,000 are to be utilised for this purpose. Further recommendations are concerned with the continuation of large-scale experiments and researches, the pursuance of a definite policy for ensuring a future supply of nitrogenous compounds, the establishment of advisory bodies in all parts of the country, the collection and publication of comprehensive statistics on the nitrogen industry and the consumption of fuel, and also the promotion of the nitrogen industry in the colonies, among which Canada and India are stated to offer the best prospects, both from the standpoint of greater manufacturing facilities and of a large agricultural demand for the product. Nitrogenous fertilisers are scarcely used at all in many parts of the Empire. This position would immediately be altered if the supply were abundant and cheap.

During the latter part of the War the British Government decided to erect their own ammonia works. An attempt was made to utilise the Haber process or rather the modification of that process worked out by Maxted at Gas Developments, Ltd., in Walsall, Staffordshire. The proposals of the Government were actually put into practice on a much larger scale than was originally intended.[2] At the conclusion of the Armistice, in November, 1918, the plant at Billingham, close to Stockton-on-Tees in Yorkshire, was quite unfinished; this plant covered an area of 109·78 hectares.[3] In 1920 these works were sold to Brunner Mond & Co., Ltd. A Government nitrogen works, such as is demanded in various quarters, does not exist in England at present, and the reports and speeches of British Ministers, many of which were very optimistic,[4] have not so far been borne out in practice.

The Report, comprising 162 pages, of the Commission for the Study of the German Chemical Industry, which was given in *The Times* of February 9th, 1920, deals, among other matters, with details of the development of the nitrogen industry during the War.

The remaining munition dumps in France were sold by the

[1] *Zeitsch. f. angew. Chem.*, ii., 301.
[2] *Chem. Ztg.*, 1920, p. 134.
[3] *Zeitsch. f. angew. Chem.*, 1919, ii., 538.
[4] *Ibid.*, 1917, iii., 131, 464; 1919, ii., 392; *Chem. Ztg.*, 1919, p. 503.

British Government to an Anglo-French combine for a sum of £2,000,000. The ammonium nitrate in these explosives [1] is used for the manufacture of fertilisers and the metallic parts are melted down. As is well known, explosives are also converted into fertilisers in Germany. In Germany operations are controlled by the Commission for Ammoniacal Fertilisers.

English interests in the Chilean nitrate industry are very extensive (see Chapter II.); not only are the head offices of many of the nitrate companies situated in London, but English merchants occupy a prominent position in the nitrate trade, due to the energy of Colonel North, who migrated from Yorkshire to Chile in 1871, and was known as the "Nitrate King." For a long period supplies of nitrate suffered very seriously through the effects of the German naval operations until these were successfully countered. An agreement with regard to nitrate supplies was concluded between the Chilean Government and the Nitrate Commission of the Allied Powers, and was signed in London on October 3rd, 1918, according to which 680,000 tons were to be delivered by the end of 1918, of which 320,000 tons in September and 120,000 in each of the three following months, at a price of 13*s.* to 13*s.* 6*d.* per cwt. Of these quantities the greater part of that portion destined for Europe arrived safely in port. A report of the British Ministry of Munitions on the production costs of nitric acid from Chile nitrate is based on a price for refined nitrate of £24 per ton and of £7 per ton for sulphuric acid.[2] The cheapest production costs were those of the large Gretna Works, which produced nitric acid at about £48 per ton; the highest were those at Queen's Ferry of £56 2*s.* per ton, and at Litherland of £55 per ton. The nitrogen yield was 95·8 per cent. Fairly large experiments were made in the works in the West Riding of Yorkshire and elsewhere, in 1915–16, in order to dispose of the sodium bisulphate (nitre cake). The nitre cake was used in place of sulphuric acid for the recovery of fat from wool-washing effluents, for purifying fats, for stripping and dyeing shoddy, and also in the tanning industry for salting the hides.

We have already referred to the fact that the English sulphuric acid industry developed considerably under the stimulus of the War. In 1913 about 7,000 tons of sulphuric acid were imported and 8,500 tons exported. The domestic production was mainly used for the manufacture of ammonium sulphate and of superphosphate, the production of the former in 1913 being 438,932 tons and of the latter 820,000 tons; also for the manufacture of chemicals, for

[1] *Metallborse*, 1920, p. 1318.
[2] *Chem. Ztg.*, 1919, p. 340.

refining oils, and finally in smaller amounts for the manufacture of explosives. With the outbreak of War these conditions were altered; the explosive industry utilised by far the great portion and the remaining industries had to be satisfied with smaller amounts. Consequently the existing plants were first largely extended, and new plants were then built to supply the Government explosive works. The present output capacity in England is far larger than the peace-time demand. It is hoped that this over-production may be utilised by increasing the production of ammonium sulphate. It is, however, hardly likely that this can be increased to a sufficient extent to absorb the whole of the sulphuric acid. The export of ammonium sulphate, which was formerly mainly supplied to Japan, Spain, Java and the United States, is now more difficult on account of the largely increased world production. Meanwhile the demand for sulphuric acid for the production of nitric acid from Chile nitrate is declining with the increasing employment of synthetic methods. The position of the future of the British sulphuric acid industry is by no means favourable. The contact process has been but little used in the new installations. The British Ministry of Munitions gives an interesting account of the production costs of fuming sulphuric acid, as a basis for which the sulphur contents of pyrites and of raw and crude sulphur are priced at £13 per ton. The process of the Verein Chem. Fabriken of Mannheim was used in the plants at Queen's Ferry, Gretna and Oldbury. The yield from the Grillo plants was on the average 94 per cent., that of the Mannheim plants was rather better, whilst the Tentelew plant only achieved a yield of 86·2 per cent. The total production costs per ton of fuming acid were [1] :—

In the four Grillo plants . .	£7 15*s*. to £8 7*s*.
In the three Mannheim plants .	£10 10*s*., £11 12*s*., and £17.
In the Tentelew plant . .	£10 10*s*.

The cascade concentrating plants worked at an average cost of £2 17*s*. per ton. The loss of sulphuric acid was given as 0·098 per cent. The cost of concentration in the Gaillard plants varies greatly. The Mannheim plants at Queen's Ferry, Gretna and Oldbury and the Grillo plant at East Greenwich were closed at the end of 1918.

The production of ammonium sulphate in England was as follows :—

1900	213,000 tons.
1910	369,000 ,,
1913 (exports : 323,000 tons) . .	438,932 ,,

[1] *Chem. Ztg.*, 1919, p. 340.

1914 (exports: 313,431 tons) . .	427,756 tons.
1915 (exports: 294,308 tons) . .	426,267 ,,
1916	433,703 ,,
1917 (exports: 62,960 tons) . .	458,617 ,,
1918 (exports: 19,044 tons) . .	262,140 ,,
1919 (exports: 94,473 tons) . .	380,000 ,,

As already mentioned, pre-war exports mainly went to Spain and Portugal (55,910 tons in 1913), to Japan (114,684 tons in 1913), to the United States (37,064 tons in 1913), and to Java (38,046 tons in 1913). In 1918–19 France absorbed a considerable proportion, whereas in 1912 Germany imported 7,665 tons, and in 1913 8,964 tons only.

British Exports of Ammonium Sulphate (in tons).

To	1918.	1919.
France	7,693	17,593
Spain	0	5,591
Italy	3,351	2,767
Netherland East Indies	0	12,854
Japan	0	39,668
Other countries	8,000	16,000

British exports to Germany were 1,843 tons in 1912 and 9,388 tons in 1913. British exports have increased further since 1920. In January and February, 1920, 20,147 tons were exported, as compared with 5,867 tons in 1919. The figures for June are as follows:—

Importing Countries.	June, 1919.	June, 1920.	1st Jan. to 1st Dec., 1919.	1st Jan. to 1st Dec., 1920.
France	360	0	—	—
Spain and the Canary Islands	568	550	—	—
Italy	825	0	—	—
Java	1,200	0	—	—
Japan	0	1,875	—	—
West Indies	302	1,785	—	—
Other countries	1,440	986	—	—
Totals	4,695	5,196	79,972	99,613

Japan, Java and Spain are the most important importing countries, whilst the United States have decreased their imports, having enormously developed their own industry. As the nitrogen famine in other countries ceases and political relations become more stable, the increased production of synthetic products will become more and more important. Nitrogen fixation plants are now at work in Spain, Italy, German-Austria, Switzerland, Holland, Czecho-Slovakia,

Yugoslavia and Hungary, although in some of these countries they are only working on a small scale. The problem of increased domestic consumption, requiring new markets, will be one of increasing difficulty to those European countries, such as the Scandinavian countries, France, Germany and England, which will depend in the future on a large export of nitrogen products.

As long as there is a nitrogen shortage on the one hand and hindrances to production on the other, the above-mentioned tendency will not be apparent, but when normal circumstances are restored, it will become a burning economic problem. The British Sulphate of Ammonia Federation, Ltd., of London, was founded in 1920 for the sale, import, export and storage of ammonium sulphate, to increase the demand for the product, to study better methods of production, and so forth.[1] In July, 1920, however, seriously diminished demands were reported, particularly from Japan, in which country the storage capacity is over-taxed and supplies are also being obtained from the United States.[2]

The English consumption of ammonium sulphate in 1913 was 105,000 tons, of which 60,000 tons were used for agricultural purposes. In 1914 15 the home consumption was 128,000 tons. In 1914–15 about 120,000 tons were produced in Scotland, and about 3,000 tons in Ireland.

The production in gas works was approximately constant from 1911 to 1916, and amounted to 170,000 to 180,000 tons of ammonium sulphate annually. Blast furnaces supply 15,000 to 20,000 tons, and the distillation of oil shale about 60,000 tons ; the production from gas producers and so forth also remained approximately constant, at about 30,000 tons. On the other hand, the production from coke ovens rose by about 50,000 tons between 1911 and 1916. It was 30,000 tons in 1905 and 166,354 tons in 1917. In 1919 632 works produced ammonium sulphate. Details are given in tons in the following table :—

	1914 (approximate)	1915	1916	1917	1918	1919
Gas works . . .	176,000	173,675	172,269	188,478	173,541	173,501
Blast furnaces . .	16,000	15,142	15,154	13,621	12,717	10,877
Oil shale distillation .	63,000	58,826	57,988	60,560	58,311	48,618
Coke ovens . .	— { 171,000	145,406	159,506	166,354	164,448	144,367
Gas producers, etc. .		33,218	28,786	29,604	23,534	20,150
	426,000 (approximate).	426,267	433,703	458,617	432,551	397,513

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 303.
[2] *Chem. Ztg.*, 1921, p. 631.

In 1916 there were 722 works in England producing ammonium sulphate, ammonium chloride, or liquid ammonia; in 1917 there were 742. In the latter year 27 works produced liquid ammonia, and 7 ceased to produce ammonium sulphate. The stocks of ammonium sulphate were 25,000 tons at the end of 1914 and 26,000 tons at the end of 1915.

38,220,000 tons of coal were coked in 1918; the production of coke in 1917 and 1918 was distributed as follows, in millions of tons:—

	1917.		1918.
Gas works . . .	8·440	..	7·945
Coke ovens . . .	13·555	..	13·121
	21·995	..	21·066

In 1918 there were 1,415 producing gas works. Many of the coke ovens were of an obsolete type, and many of these were not adapted for the production of by-products. In 1911 there were in England 143,000 beehive ovens producing 5,600,000 tons of coke, and only 6,524 by-product ovens producing 8·2 million tons, or 60 per cent. of the total. The annual loss of by-products thus incurred was estimated at 70,000 tons of ammonium sulphate, 250,000 tons of tar, and 54,000 to 68,000 cu. m. of benzole. In 1915 there were 211 coke ovens, of which 116 were by-product ovens. There were 16,574 working coke ovens of the most various construction. The figures for the various types were:—

	1914.			1915.	
Beehive ovens .	9,210		..	7,521	
Coppée ovens .	1,538		..	1,343	
Simon Carvès ovens	1,354		..	1,766	
Otto-Hilgenstock ovens	1,589		..	2,034	
Semet-Solvay ovens	1,134		..	1,251	
Koppers ovens . .	866		..	1,241	
Simplex ovens . .	428		..	486	
Hüssener ovens . .	384		..	404	
Bauer ovens. . .	43		..	40	
Collins ovens . .	95		..	171	
Mackey-Seymour ovens	32		..	32	
Other types of ovens .	302		..	285	
Total by-product ovens	7,765	16,975		9,053	16,574
,, beehive ovens	9,210			7,521	

By the end of 1914 there were 7,813 by-product ovens at work which treated 15,000,000 tons of coal annually, that is, 1,900 tons per oven per year; at the end of 1918 there were 9,827 working

by-product ovens treating 21,000,000 tons of coal per year, or 2,031 tons per oven per annum. In 1918 there were 201 coke oven plants, of which 116 were by-product plants as compared with 123 in 1917. The by-product plants treated 21,000,000 tons of coal, and the others only 2·6 million tons of coal, whilst the gas works treated 14·6 million tons, so that practically the whole of the coal which was coked was treated under conditions enabling the by-products to be recovered. Compared with the astonishing development of the American industry during the War the English coking industry was relatively very unprogressive. England was short-sighted enough to support this competition. Such high prices were paid in England for the American coke oven by-products that the American industry was in a position to write off the new installations within one to two years, and to continue work with the most modern and profitable plants.

As the production of coke will probably considerably exceed the demand when normal conditions are restored, the coke producers of Yorkshire, Derbyshire, Staffordshire, Wales and Lancashire decided to establish a joint sales organisation. This Blast-Furnace Coke Sales Association (1919) also controlled other manufacturing conditions. The development of the by-product coking industry has been especially marked in the Cumberland coalfield. At the commencement of March, 1919, there were 380 by-product ovens in that district, producing annually 650,000 tons of coke, 12,000 tons of ammonium sulphate, 40,000 tons of tar, and 3,000,000 cu. m. of crude benzole. In Halifax there were produced on the average, between 1907 and 1917, 11·6 kg. of ammonium sulphate per ton of coal, and 13·8 kg. in 1918.

English investigations on the low temperature carbonisation of coal can only be considered here very shortly. This question was investigated by a Government Commission which emphasised the economic importance of the problem. According to a paper read by Edgar C. Evans at the Annual Meeting of the Society of Chemical Industry in 1918, the investigations and patents of Becker and Serle in 1681 (the first English patent law dates from the reign of James I. in 1623), of Scott Moncrieff (1890), Parker (British Patents 67/1890; 14,365/1906), Wheeler, Lomax, Stopes, Hickling, Renault, Bertrand, White, Jeffreys and Thiessen, are important as the foundations on which the later developments were based. The solution of the problem is being attempted in England by three systems, which are distinguished by the type of oven which they utilise :—

(1) Discontinuous charging of externally heated retorts.

(2) Discontinuous charging of internally heated retorts.

(3) Continuous charging by passing the coal automatically forward through the retort, with either internal or external heating, or both.

The retorts of the "Coalite" system (type 1) were a failure, as the constitution of coal was as yet insufficiently understood. Satisfactory results were only obtained when the coal was treated in thin layers. In the Tozer retort of the Tarless Fuel Company, the layer of coal is never thicker than 10 to 12½ cm. The charges are larger, the working costs are smaller, and the yields are better. The process of the Tarless Fuel Company has, however, not yet been able to demonstrate its advantages on the large scale. The Barnsley Smokeless Fuel Company works with vertical retorts of fireclay. The Simpson process works under a vacuum (50 to 65 cm. of mercury), which has many chemical advantages, but many technical disadvantages.[1]

In the experiments of the Coalite Company, Ltd., 3¼ tons of ammonium sulphate were obtained from 200 tons of coal. In 1919 the Coalite Company was absorbed by Low Temperature Carbonisation, Ltd., with a capital of £1,200,000, which claimed to produce, by a low temperature carbonisation process, the following quantities of by-products per ton of coal: (1) 72 to 77 litres of lighting and lubricating oil; (2) 13 to 18 litres of motor fuel of better quality than petrol; (3) about 200 cu. m. of illuminating gas of calorific value 6,230 cals.; (4) 9 kg. of ammonium sulphate and 0·71 tons of smokeless fuel, which is superior to raw coal for domestic heating and for firing boilers. In the Tozer retort of the Tarless Fuel Company, 1 ton of coal is heated from 380° C. to 540° C., yielding the following products: (1) 113 to 169 cu. m. of illuminating gas of 5,785 cals.; (2) 6·8 to 10·0 kg. of ammonium sulphate; (3) 80 to 100 litres of tar oil; and (4) 0·7 to 0·75 tons of coke residue, which is neither readily friable nor liable to crumble, and which contains 9 to 12 per cent. of volatile ingredients. The so-called Carbocoal process[2] yields per ton of coal (containing 30 per cent. of volatile matter) at 427° and 982° C., apart from gas: (1) 0·75 tons of coke briquettes, so-called "carbocoal"; (2) 11·4 litres of motor spirit; (3) 4·5 litres of light naphtha; (4) 9 litres of heavy naphtha; (5) 19·31 litres of tar acids; (6) 28·4 litres of burning oil (in all 72·6 litres of oil and similar products); and (7) 15·6 kg. of ammonium sulphate. The steam-raising trials carried out by the Pennsylvania Railroad Company with carbocoal show that this produced 11·1 times its weight of steam with a thermal efficiency of 86·2 per cent., whilst with crude coal

[1] See Bertelsmann in Ullmann's "Encyclopædia," vol. vii., pp. 234 *et seq.*
[2] *Chem. Ztg.*, 1919, pp. 7, 36; 1920, p. 25.

only 10·87 times its weight of steam was obtained with a thermal efficiency of 81·1 per cent.; 80·7 kg. of carbocoal were burnt per hour without smoke production per 1,000 sq. cm. of grate area. The Midland Coal Products Company, Ltd. (£100,000 capital), is a research organisation on a practical basis, which investigates low-temperature carbonisation questions in large experimental plants. In 1913 there was founded the Carboyl Syndicate, Ltd., with a capital of £500,000, which has envolved a process by which the production of coke and briquettes is entirely dispensed with, and by which waste coal is converted entirely into oils and ammonium sulphate. The Report of the Commission formed by the Ministry of Munitions estimates that a yield of 1,000,000 to 1,250,000 tons of oil may be obtained on the average from each 20,000,000 tons of coal which is coked. In March, 1918, J. T. Dunn lectured before the Coke-Oven Managers Association on the various coking processes.[1]

The study of these questions is also undertaken by the experimental station at East Greenwich, which was erected adjoining the works of the South Metropolitan Gas Company. In English gasworks, the scarcity of coal during the War, its poorer quality, and the removal of the benzole, resulted in a considerable reduction of the thermal value of the gas, from 560 B.T.U. (4,984 cals.) to 500 or even 420 B.T.U. (3,965 cals.). The coal-gas was usually mixed with blue water gas (up to 33 per cent.), and in some cases with flue gases ($CO_2 + N_2$) (up to 30 to 40 per cent.), and possibly in the future a calorific value of 4,450 cals. will be considered suitable as an average.[2] The very modern gas works at Birmingham utilises 7-ton retorts, and comprises a cyanide plant using Williams' process, which treats 283,000 cu. m. of gas daily. The yield of ammonium sulphocyanide is 90 per cent. By injecting steam into the retorts, the yields of ammonia and tar can be increased. Attempts to obtain ethylene directly from lighting gas by direct condensation, are becoming of increasing importance in England. Yields of 98 to 99 per cent. are claimed, and it has been calculated that the amount of ethylene obtainable in England by these means would suffice for the production of about 680,000 cu. m. of 90 per cent. alcohol per annum, of which 1 gallon (4·54 litres) has a value of 1*s.* 3*d.* When mixed with equal parts of benzole this alcohol furnishes an excellent fuel. As in England, with its lack of suitable water-powers, the production of alcohol from calcium carbide does not seem particularly promising, the above-mentioned method may become important. Lighting gas contains 4 to 5 per cent. of ethylene,[3] coke-oven gas

[1] *Chem.-Ztg.*, 1918, p. 431.
[2] *Journ. f. Gasbel.*, 1918, p. 210.
[3] G. Cohn in Ullmann's "Encyclopædia," vol. ii., p. 9.

contains appreciably more, American natural gas 15 to 16 per cent., and in some localities 19·5 to 22·5 per cent. P. Fritzsche obtains ethylene from washed gases by treatment with concentrated sulphuric acid (German patent 89,598).[1] Ellrodt [2] writes on the further treatment of the ethyl sulphuric acid by heating with water, with regeneration of the sulphuric acid according to the following equations :—

$$C_2H_4 + H_2SO_4 = C_2H_5 . O . SO_3H$$
$$C_2H_5 . O . SO_3H + H_2O = C_2H_5 . OH + H_2SO_4.$$

He points out that these processes were already discovered by Faraday's co-worker, Hennel, in the years 1825–28; Hennel obtained "vinyl-sulphuric acid" from lighting gas and oil gas. M. Berthelot [3] studied the reaction more closely in 1855, and it was then investigated by C. Fritzsche [4] from the technical standpoint. According to Fritzsche's investigations, 100 kg. of hot sulphuric acid absorb 14 kg. of ethylene, from which 18 kg. of 100 per cent. alcohol can be obtained. At that time the practical application of the process was impossible owing to the considerable loss of sulphuric acid, namely, 450 kg. per hectolitre of alcohol. A more favourable result might be obtained by the improvement or alteration of the method of working, especially as the process must arouse the interest of all countries with large coal resources, such as England, Germany and America.

During the War Professor Cobb devised a process in England in order to utilise the sulphur in coal for the production of ammonium sulphate.[5] The gas is treated with zinc sulphate solution in a centrifugal washer. The zinc sulphide precipitate is filtered and the ammonium sulphate solution which is so obtained is evaporated (cost of evaporation ?). The sulphide is roasted. The roaster gases are reconverted into zinc sulphate by a suspension of zinc oxide in water. Accompanying tar products do not interfere with the roasting, as they are burnt ; the residues of zinc oxide are utilised for the further production of zinc sulphate. The process has proved quite successful in the laboratory and in small installations. Since the end of 1919 a larger plant has been in daily operation for the production of 1 ton of ammonium sulphate per day.

When discussing the cyanamide industry in Norway and Sweden, we considered in detail the works at Odda and Alby which were

[1] *Chem. Ind.*, 1912, p. 637.
[2] Ullmann's "Encyclopædia," vol. i. (1914), p. 637.
[3] *Compt. rend.*, **40**, 102 ; *Ann. de Chim.* (3), **43**, 385.
[4] *Loc. cit.* and *Chem. Ind.*, 1897, p. 266.
[5] *Chem. Ztg.*, 1919, p. 806.

absorbed by the Nitrogen Products and Carbide Company, Ltd., of London, and its affiliated companies. The Nitrogen Fertilisers Co., Ltd., which was formed in 1912, with a capital of £200,000, acquired a licence from the North-Western Cyanamide Co., Ltd., of Odda.[1] The Nitrogen Products Company was founded in May, 1913.[2] It took over in 1913 the works at Vilvorde in Belgium, erected by Duché, in which attempts were first made to oxidise ammonia from Norwegian cyanamide with production of ammonium nitrate by Ostwald's catalytic process. The rights to work the Ostwald process, which had belonged to Nitrate Products, Ltd., and were valued at £369,500, were also transferred to the Nitrogen Products Company in 1913. The works at Odda were closed at the outbreak of War, but in December, 1914, manufacture was resumed to the extent of 40 per cent. of the capacity of the works. The granulating department produced "granular nitro-lime," that is, granulated cyanamide for agricultural purposes. In 1915 it was considerably extended. The works at Vilvorde to the north-east of Brussels were soon affected by the War in 1914, and consequently stopped production. Experience had already shown, however, how difficult it is satisfactorily to oxidise ammonia from cyanamide to nitric acid. In consequence of these difficulties the scheme of erecting two nitric acid works on the Thames and in Manchester, for the purpose of producing nitric acid from Norwegian cyanamide, for the English explosive industry, was abandoned. It was, on the other hand, decided to manufacture ammonium perchlorate for military purposes. Later, however, the original scheme was once more taken in hand.

In 1916 the British Ministry of Munitions concluded an agreement with the Nitrogen Products Company for the delivery of ammonium nitrate and nitric acid. It is understood that 8,000 tons per annum of the former product were to be supplied. A loan of £50,000 at 5 per cent. interest was agreed to for the acquisition of the necessary plant, and this was to be repaid by deductions from the price of the materials which were delivered. The new plant was erected at Dagenham, where the Nitrogen Products Company had been working since 1913; production was started in 1916-17. In spite of good reports at the commencement, exceptional difficulties were met with. The original Ostwald process was first altered by the Chairman of the Nitrogen Products Company, A. E. Barton, but even so, all the expectations were not satisfied. Difficulties in the supply of Norwegian cyanamide led of necessity to its replacement by ammonia from gas works, which was too expensive. In 1917 the working losses

[1] *Chem. Ind.*, 1912, p. 294.
[2] *Chem. Ztg.*, 1913, p. 703.

had already amounted to £75,000. In spite of this expenditure, no serious quantities of any product had been manufactured, so that finally, in 1918, the Ministry of Munitions refused to supply any further public money. Meanwhile the Nitrogen Products Company had granted licences in France, Italy and the United States, or had entered into negotiations for granting the same. The French works at Angoulême started manufacture before the Dagenham works (see Chapter VIII.); it is said to work satisfactorily. An Italian plant was said to be under construction in 1917, but no further details have become available.

Attempts to combine the Nitrogen Products and Carbide Company and the Alby United Carbide Factories were started in 1918; these companies carried on practically the same business, and were united by numerous financial interests. The conditions demanded by the Norwegian Government rendered the amalgamation difficult, and it was only effected on November 11th, 1919, by decision of a general meeting in London. This finally removed the difficulties, which were due to the fact that the Alby United Carbide Factories were under agreement to supply a large proportion of their carbide production to the cyanamide works of Nitrogen Fertilisers, Ltd., at Odda in Norway, this latter being in turn an affiliated company of the Nitrogen Products Company. The Nitrogen Products and Carbide Company, which was founded in May, 1913, was thus absorbed by the Alby Company, and ended its career as a separate firm. In 1918-19 the Vilvorde plant was valued by the Company at £138,100, and the Odda Works at much under their actual value. The compensation claim of Nitrogen Fertilisers, Ltd., for the destruction at Vilvorde and elsewhere, was recognised by the German Government, which paid £270,000. Revenues from the granting of licences appeared in the balance sheet for 1918-19 in reference to the French works at Angoulême only, from which it may be gathered that the proposed sale of licences in Italy and the United States had not been realised. In the report the losses at Dagenham are said to be due to the fact that the plant was obliged to use the more expensive ammoniacal liquor from gas works. This caused endless difficulties in the works, which were not adapted for the use of this product, and the final product was dearer than was justified by the Government contract, which was based on cost of manufacture from cyanamide. It was also stated that the Government created many difficulties regarding the supplies of ammoniacal liquor, the production of which was controlled by them during the War. During the last few years the Nitrogen Products and Carbide Company have paid 6 and 9 per cent. dividends. The Alby Factories paid

$5\frac{1}{2}$ and 6 per cent. dividends in 1918. The North-Western Cyanamide Company at Odda also paid a 15 per cent. dividend. Nitrogen Fertilisers, Ltd., disposed of their interests in the Alby Works at a good profit, but retained the principal interest in the Odda Works. The A.S. Meraker now produces ferro-alloys only. Electrodes are manufactured in a new works at Hebburn-on-Tyne. A number of valuable patents, for example, for compressed acetylene, have been transferred to affiliated companies. Since 1914 the Alby Company has suffered from works difficulties and from the effects of an unfavourable long-period contract for the delivery of carbide. It was, therefore, only able to pay a 5 per cent. dividend in the first three War years, and no dividend at all in 1917.

The fusion of the two main companies, the Nitrogen Products and Carbide Company and Alby United Carbide Factories, Ltd., the assets of which have just been described, was carried out by the issue by the Alby Company (which had a capital of £82,916 in preference shares and £643,084 in ordinary shares), of £1,607,916 in new ordinary shares, of which £1,499,965 were utilised for the purchase of the shares of the Nitrogen Products Company. As the Alby Company already held £500,035 in shares of the latter company, its whole capital passed into their hands for the sum of £2,000,000. The Nitrogen Products Company was liquidated.

The united companies now control 700,000 h.p. from water-powers, namely, 65,000 at Odda, 250,000 at Aura (both in Norway), and at least 400,000 h.p., still unutilised, at Dettifoss, in Iceland. The Alby Works, together with the power station Alby-Vattenfalls, was acquired towards the end of the War by the purely Swedish Stockholms Superfosfatfabriks A.B., for a payment of 2·5 million kr. in Alby shares.

The English company expect exceptional results from an increase in the use of nitrogenous fertilisers, and believe that cyanamide in the form of the product of their Odda factory, namely, "granular nitro-lime," will have an exceptional future, as, on the one hand, English farmers have now realised the value of artificial fertilisers, and, on the other hand, the lime in calcium cyanamide should be advantageous, as when introduced into the soil it will compensate for the lime which is removed, for example, by the use of ammonium sulphate. It should be noted that German opinions on granulated cyanamide have hitherto been unfavourable. According to Harrison,[1] calcium cyanamide and ammonium salts are the only fertilisers which are suitable for the cultivation of rice and cane sugar. In India alone the average area under rice is 312,000 sq. km.,

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 333.

and that under sugar about 10,100 sq. km., so that large prospective markets are available which have not so far been supplied. In Java and Hawaii respectively, 4 tons and 9 tons of sugar are produced per acre with the help of artificial fertilisers, whereas in India, where agriculture is in a more backward condition, only about 1 ton is obtained from the same area. The united English companies propose to carry out at their Norwegian works all those industries which require little or no coal. It is stated that recent investigations will have the effect of decreasing considerably the manufacturing costs of carbide and cyanamide. It is hoped that phosphatic and nitrogenous fertilisers will also be obtained electrically. Experiments are being carried out on the most suitable method of manufacturing cyanides.

The attempts of the Nitrogen Products Company to transfer the cyanamide industry to England are of still greater interest than the above-mentioned programme. According to C. R. Darling [1] there are required for the production of 1 ton of carbide 4,000 k.w.h., which cost about 25·50*s*. in Norway (1 k.w.h. = 0·64 pfg.), and 118·32*s*. in 1918 in England, from coal (1 k.w.h. = 2·96 pfg.). It would therefore be difficult to carry out the manufacture of carbide in England in competition with the foreign product. Charles Bingham [2] suggests the use of blast furnace or coke oven gas for the manufacture of carbide. The following remarks on these proposals were made by the Chairman of the Nitrogen Products Company at the General Meeting on May 8th, 1918.[3] "In order to render England independent of supplies of these nitrogenous compounds, which are important both in peace and in war, the introduction of ample and cheap electric power is absolutely necessary. During the last two years the company has undertaken experiments in this direction involving the carbonisation of 1,000 tons of coal. These have led to the conclusion that these industries can only be established in England if the various processes are so co-ordinated that the by-products of the one may serve as a raw material for the other. It is also essential that the power and these manufactures should be in the same hands and under one direction. Cheap electrical energy can only be obtained by the acquisition of a large coal mine, the coal of which must be carbonised on a sufficiently large scale at a high temperature, so that all the by-products are recovered and the rich gases used for raising steam to drive steam turbines for the production of electric power. The production of by-products—

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 618.
[2] *Loc. cit.*
[3] *Zeitsch. f. angew. Chem.*, 1918, iii., 333; *Financial News*, May 9th, 1918.

benzene, toluene, naphtha, carbolic acid, cresole oils, creosote and anthracene oils—should cover at least half the domestic requirements. A portion of the toluene could be used for the production of explosives. For this project 120,000 h.p. would be necessary, which would be utilised to produce carbide, cyanamide and ferro-alloys, and also to treat zinc concentrates. It is maintained that the successful working of such a project would make England completely independent of the importation of Chile nitrate, as all the nitric acid, ammonia and so forth, for military and industrial purposes would be obtained from the cheaper domestic cyanamide production. The farmer would obtain a nitrogenous fertiliser which would be as effective as nitrate and also cheaper. The realisation of this idea requires large means and is at present (May, 1918) impossible. All the data are, however, being worked out for a plant of 120,000 h.p., so that in peace time the construction of such a plant may be commenced if possible." At the commencement of 1919 the Nitrogen Products Company, Ltd., acquired the St. Helens Coal and Firebrick Company, Ltd., for a payment of £12 for each £5 of share capital, and also large neighbouring lime quarries in Eskett and Rowah. The St. Helens Colliery is at Workington, Cumberland, and has a battery of forty coke ovens. It is said that there is now being added to these coke ovens a new cyanamide plant which corresponds in all respects to the above-mentioned project; [1] 3,000 tons of coal are to be treated daily, and all the by-products are to be recovered and utilised. Distillation is to be carried out at high temperatures, so that the production of low-temperature tar is not considered. Gas and coke are to be used under boilers and in gas engines for the production of power, carbide and cyanamide. The turbines are to develop 120,000 h.p. The capital which is to be employed, amounts to £5,500,000. The construction of the works, which will finally employ 4,000 men, is estimated to take two and a half years, so that it should be finished in 1921–22; 120,000 h.p. should suffice for a production of about 180,000 tons of carbide per annum, so that the output will be very considerable. It is intended that the plant should render Great Britain independent of the importation of foreign nitrogenous fertilisers. The practical result of this scheme (the Cumberland Coal, Power and Chemical Company, Ltd., Workington), will be of all the more interest as it will enable interesting conclusions to be drawn with regard to similar possibilities in Germany. The Cumberland Company has also acquired the rights to work the Claude process (see below).

In 1918 the British Cellulose and Chemical Manufacturing Com-

[1] *Chem. Ztg.*, 1920, p. 152.

pany was building a plant for the manufacture of synthetic aldehyde, alcohol and acetic acid.

The firm of Brunner Mond & Co., Ltd., established in 1881, has taken an active interest in the nitrogen industry; in 1917 this company had £1,500,000 of preference share capital, and £2,900,000 of ordinary share capital. The total nominal capital at that date was £5,000,000, and the average dividend during the last few years was 30 to 35 per cent. According to Wilh. A. Dyes[1] the Stock Exchange valued the undertaking in 1916–17 at £10,000,000. This important firm was the first in England to manufacture ammonium nitrate on a large scale. When the British War Office realised in 1915 that the demand for explosives could not be covered by trinitrotoluene and lyddite only, but that ammonium nitrate would have to be manufactured, it was not being produced in England at all. At first the Ministry of Munitions bought calcium nitrate from Norway, which Brunner Mond & Co., Ltd. converted into ammonium nitrate with ammonium sulphate according to the reactions already mentioned. The amount so obtained soon proved to be quite insufficient. Brunner Mond & Co., Ltd., then worked out another method on the lines of the ammonia soda process starting from Chile nitrate. After a couple of months these supplies were also insufficient, and attention was turned to the direct double decomposition of sodium nitrate and ammonium sulphate. This process was then carried out in the works of the firm and in a considerable portion of the plant of another firm, and hundreds of tons of ammonium nitrate were manufactured daily. Finally a successful synthetic process was produced which presumably mainly used by-product ammonia, but possibly also a modified Haber process on the smallest scale, and this was to supply ammonium nitrate and nitric acid by the oxidation of ammonia. On behalf of the Government, Brunner Mond & Co., Ltd., undertook the construction of a portion of the large Government works at Billingham-on-Tees, which was to be constructed for a production of 2,000 tons of ammonium nitrate weekly by this process. On information communicated by the Ministry of Munitions in 1918, other works also started to use the ammonia oxidation process, more particularly a number of gas works. It is expected that ammonium nitrate will be in considerable demand as a fertiliser under peace conditions, as it contains 35 per cent. of nitrogen. Brunner Mond & Co., Ltd., also erected a trial unit for ammonia oxidation of the American Jones-Parsons type, which was used later in the enormous American plant at Muscle Shoals.

[1] *Chem. Ztg.*, 1917, p. 235.

The Committee of the Ministry of Munitions was always in favour of the erection of by-product and synthetic plants in order to render England as far as possible independent of foreign supplies of fixed nitrogen. It was therefore decided to continue work on the plant at Billingham, which was still quite unfinished at the signing of the armistice, and these works were offered for sale to private interests in 1919. Investigations had shown that the industrial production of synthetic ammonia would be rendered possible by alterations in the plant of a not very serious character. The Government works were offered for sale on condition that the purchaser undertook the obligation successfully to develop the fixation of atmospheric nitrogen, and to produce sufficient quantities of nitric acid for the production of explosives for the Army and Navy. The Government also reserved control over the works and a certain influence on the appointments to leading positions.[1]

On the basis of these conditions the sale was effected at the commencement of 1920. Brunner Mond & Co., Ltd., took over the works, founding for the purpose Synthetic Ammonia and Nitrates, Ltd., with a capital of £5,000,000.[2] The works are at first to be equipped for a daily production of 100 tons of HN_3, which is rapidly to be increased to 300 tons of NH_3 per day, corresponding to 150,000 and 450,000 tons of ammonium sulphate per annum respectively. Apart from ammonium sulphate the main product is to be ammonium chloride, which will be obtained by the ammonia soda process. It is hoped that agricultural interests will view favourably the use of ammonium chloride as a fertiliser, as it will be sold to them at a very low price. Explosives Trades, Ltd., have undertaken to draw their supplies of ammonia from the new works and to erect plant for the oxidation of this ammonia to nitric acid.

Brunner Mond & Co., Ltd., have undertaken detailed inspections of the works at Oppau, of the American Government works at Sheffield, Ala., of the General Chemical Company's works at Laurel Hill, N.Y., and also of the experimental plant working the Claude process at La Grande-Paroisse. The experimental works of Dr. E. B. Maxted, at Gas Developments, Ltd., already referred to, were acquired by purchase, together with all patents associated therewith. The company intends to utilise a modified Haber-Bosch process, which is stated to have been developed entirely without German help. The British Government has granted a licence to use the relevant patents of subjects of foreign (*i.e.* German) States, on terms which are to be deducted from the reparations due according to the Peace Treaty of

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 301.
[2] *Ibid.*, 1920, ii., 249.

Versailles. Synthetic Ammonia and Nitrates, Ltd., of Billingham, near Stockton-on-Tees, Durham, is taking over the whole staff of the nitrogen department of the firm of Brunner Mond & Co., Ltd., and is organising a large technical staff.

At the British Scientific Products Exhibition in 1918 Brunner Mond & Co., Ltd., exhibited ammonium nitrate and other products.[1] They controlled nine different works for the manufacture of ammonium nitrate, which produced in all 378,395 tons for the manufacture of amatol. The English production of ammonium nitrate finally exceeded 5,000 tons per week ; by far the greater part of this was obtained from sodium nitrate by double decomposition with ammonium bicarbonate or by one or the other of the above-mentioned reactions. The main works were at Lostock, near Northwich. The large Victoria Works at Wincham, Cheshire, supplied calcium nitrate, from atmospheric nitric acid, for conversion into ammonium nitrate. The Sandbach Works of Brunner Mond & Co., Ltd., utilised the double decomposition of ammonium sulphate and sodium nitrate for the production of ammonium nitrate. Brunner Mond & Co., Ltd., have recently absorbed the Castner-Kellner-Alkali Company, Ltd., founded in 1895 ; this latter company had in 1917 £750,000 share capital and £190,000 debenture capital.

Sodium nitrate is being refined by a new process in the works of the Salt Union at Western Point.

The Claude process has been acquired by the Cumberland Coal, Power and Chemical Company, Ltd., which has already been referred to as having been formed by the Nitrogen Products Company. The territory licensed by them includes Great Britain, South Africa, India, Australia and New Zealand. The plant at Workington in Cumberland will at first produce about 12,000 tons of NH_3 annually by the Claude process, which will partly be converted into ammonium chloride by the ammonium soda process and partly into sulphate.

Cyanides are manufactured by the Cassel Cyanide Company, of Glasgow, and the British Cyanides Company, of London. The former company doubled their capital during the War, and proposed in 1920 gradually to increase it from £175,000 to £600,000 ; for this purpose new shares to the value of £175,000 are immediately to be issued. In twenty years (ending 1916), 860 per cent. had been paid in the form of dividends—*e.g.*, 80 per cent. in 1913–14, 55 per cent. in 1914–15, 60 per cent. in 1915–16, 60 per cent. in 1917–18, and 40 per cent. in 1918–19. The British Cyanides Company, of London, increased their capital in 1920 to £450,000. The company has extended its works at Pope Lane and Tat Bank, and has thus

[1] *Chem. Ztg.*, 1918, 599.

doubled the output of the former and trebled that of the latter. A research laboratory has also been built. It is intended to construct a plant for the utilisation of atmospheric nitrogen.

German exports of sodium and potassium cyanide amounted to 6,300 to 6,700 tons in 1910–13, and had a value of £412,500 to £462,500; from one-quarter to one-third of this amount was exported to South Africa, into which country the imports of cyanide were valued at £362,500 in 1914. When the imports of German cyanide ceased in 1914 the position of the South African gold industry was at first difficult.[1] Endeavours were immediately made to increase the English cyanide imports and to establish a local industry. England exported 7,000 tons of cyanide in 1913, 8,000 tons in 1914, and 11,270 tons in 1915.[2] The two leading English companies have assured themselves of the market in South Africa and Rhodesia by a contract extending five years beyond the conclusion of peace. In 1916 it was already stated that it would be difficult for Germany to regain the lost market, but the considerably increased American competition was feared; and America supplies, for example, the whole of the Mexican requirements. In spite of this the Cassel Cyanide Company anticipates a gradual improvement in the Mexican demand. During the War the English works were able to supply all demands, which had, however, decreased on the whole by about 20 per cent. The German anticipations of a considerable reduction in the production of gold in South Africa in consequence of the cessation of the German cyanide deliveries have not been fulfilled, according to a statement at the General Meeting of the Cassel Cyanide Company on December 12th, 1918.[3] In any case the South African mines are not proposing for the present to work at full capacity with low-grade ores. The enlargement of the plant of the Cassel Cyanide Company was promoted by the Government to such an extent that it is greater than the requirements of the market. At the British Scientific Products Exhibition in 1917 the British Cyanide Company exhibited the following British potash products: K_2CO_3, $KHCO_3$, KCl, $KMnO_4$, K_4FeCy_6, and others. The National Research Syndicate was founded in London by the directors of the British Cyanides Company, Nobel's Explosives Company, and Chance and Hunt in 1918 for the study of processes of fixation of atmospheric nitrogen.

H. N. Morris & Co., Ltd., Middlewich, who electrolyse sodium chloride, propose to utilise their by-product hydrogen for the pro-

[1] *Chem. Ztg.*, 1914, p. 1113.
[2] *Ibid.*, 1917, p. 237.
[3] *Zeitsch. f. angew. Chem.*, 1919, ii., 15.

duction of ammonia. Their plant in Manchester for the production of atmospheric nitric acid, which utilises 15,000 h.p., has already been referred to.

In the middle of 1917 Joseph Sankey & Sons, Ltd., of Bilston, Staffordshire, produced a process for obtaining elementary nitrogen from air, which they are now endeavouring to utilise for the production of nitrogenous fertilisers. The following new firms and companies are also active in connection with the nitrogen industry: the Organic Ammonia Co., Ltd. (1915); the Nitrogen Recovery Company (1916); Capron Neutral Sulphate of Ammonia Syndicate, Ltd. (1917) ("Capron" Process); Tinogen Products Co., Ltd., (1917); Nitro-Fixation Syndicate, Ltd. (1918; Research Organisation); Fertilisers Manufacturers Association; Elstree Chemical Works, Ltd. (1920); Gasonite Co., Ltd. (1920); Anglo-American Nitrogen Co., Ltd. (1920); Adams Webster & Co., Ltd. (1920); Fertilisers Co., Ltd. (1920); British Sulphate of Ammonia Federation Ltd. (1920), and others.

The first British plant for the production of liquid air was erected in 1907. In 1918 there were eight such plants, and a further two plants which had hitherto manufactured oxygen with the help of barium peroxide. The two old barium peroxide works of the British Oxygen Company have now been transformed for the production of electrolytic oxygen.[1] The total oxygen production increased by about 25 per cent. in 1917. In 1919 there were twelve works, which together produced 118 tons of liquid air per day; 85 per cent. of this output was used for the production of oxygen for welding, and 15 per cent. for medical purposes. In Germany individual plants produce 100 tons daily.[2] The use of liquid oxygen explosives is still in its infancy in England.[3]

Hydrogen is produced by various companies, including Gas Developments, Ltd., Walsall, which has already been mentioned,[4] which uses a process due to its director, Maxted. This company erects fat-hardening works, and has, as is well known, carried out the first large-scale experiments by a modified Haber process. Hydrogen plants are also built by R. and J. Dempster, Ltd., Manchester. The Hydrogen and Oxygen Plant Co., Ltd., which was founded in 1919, with a capital of £50,000, holds patents by White and Jaubert for the production of oxygen and hydrogen, including German pats. 194,327, 223,246, 241,712, 241,929, 243,367, 262,635,

[1] This is erroneous.—TRANSLATOR.
[2] This should probably read "100 tons of *oxygen* daily."—TRANSLATOR.
[3] The British production of oxygen in 1923 was 12,000,000 cu. m., the greater part of which is manufactured by the British Oxygen Company, Ltd.—TRANSLATOR.
[4] *Chem. Ztg.*, 1918, p. 244.

262,728, 272,609; English pats. 12,427/1911, 5,005/1913; French pat. 454,616; it works to some extent in conjunction with the Société l'Oxylithe. The Integral Oxygen Co., Ltd., London, with a capital of £16,000, builds plant for the electrolytic manufacture of oxygen and hydrogen. The Knowles Oxygen Company, of Wolverhampton, supplies hydrogen in large quantities to the Sunlight Soap Works.

The Liquid Air and Rescue Syndicate, Ltd., of Park Royal, had a considerable surplus of liquid air available in 1919, which was supplied free of cost for experiments in order to widen the field of use of the product in chemical industry. Sparklets, Ltd., of London, with a capital of £300,000, absorbed Aerators, Ltd., in 1919, and manufacture liquefied and compressed gases.

The first attempts to gasify peat, with recovery of ammonium sulphate and so forth, were carried out in England, where the Mond gas process has been established for a considerable time.[1] N. Caro and A. Frank, who hold German Patents 238,829 and 255,291, approached the English industrialist, L. Mond, with a view to interesting him in this matter. At Mond's Works at Stockton, yields of 2·8 kg. of ammonium sulphate and 250 cu. m. of power gas of 1,300 cals. per cu. m. were obtained per 100 kg. of water-free peat, containing 1 per cent. of nitrogen. A second plant was installed at Winnington, and supplied, per ton of dry peat, 55 kg. of ammonium sulphate and 1,780 cu. m. of gas of 1,360 cals. per cu. m. By utilising this gas, a kilowatt hour can be obtained at a cost of less than 0·5 pfg. (0·04*d.*). From a peat containing 2·8 per cent. of nitrogen, 110 kg. of ammonium sulphate were obtained at Stockton per ton of dry peat, corresponding to 83 per cent. of the nitrogen.[2]

The Woltereck process, which was operated at a works in Ireland, consists of passing air saturated with steam over peat briquettes in heated retorts at a temperature not exceeding 550° C.[3] Slow combustion is thus produced without any appearance of flame. Woltereck was of opinion that in this process atmospheric nitrogen is partially converted into ammonia by the catalytic action of the peat. Caro rightly takes the opposite view.[4] Although Woltereck obtained power gas and ash, which may be used as a fertiliser, together with paraffin, acetone, acetic acid, and so forth, this process did not meet with any technical success.

In 1903 M. Ekenberg produced a process for the preparation of

[1] *Chem. Ind.*, 1912, p. 294.
[2] *Ibid.*, 1908, p. 580; 1910, p. 1015, 1911, pp. 505, 515.
[3] *Ibid.*, 1908, pp. 189, 941, 1143; 1909, p. 277; 1912, p. 1403
[4] *Ibid.*, 1909, pp. 350, 413, 483, 541; 1910, p. 1334; 1911, pp. 5, 133, 207, 734, 789.

peat charcoal.[1] He was first assisted by the Swedish Government, until in 1906 the method was found to be uneconomical. After the invention had been perfected International Carbonising, Ltd., was founded in London, in April, 1907, with a capital of £41,000, and acquired a licence for a royalty of 6*d*. per ton produced. Since March, 1909, it has worked in conjunction with the Ekenberg Peat Fuel Syndicate, Ltd., which has erected a large works at Dumfries Moor in Scotland, and issued 35,000 7 per cent. preference and 1,400 ordinary shares and in the interval has increased its capital by a further £50,000. After the death of Ekenberg, N. Testrup and E. Bowran formed the Peat Coal Investment Co., Ltd., in December, 1910, in order to acquire the patents from his executors. International Carbonising Ltd., and the Ekenberg Peat Fuel Syndicate were absorbed by Wet Carbonising, Ltd., which was founded on April 2nd, 1912, and has been very active. (See German Pats. 161,676, 169,117, 172,102, 264,002, 268,720, 268,721, 269,333, 269,741, 275,091; French Patents 451,687, 451,711, 455,896 and others.). This company has acquired the Danish peat bog of Aamosen [2] through an affiliated company called Aamosen, Ltd., London. New machines have been erected at the works at Ironhurst, Dumfriesshire, and should have been fully active in 1913–14. After the actual production costs of peat charcoal briquettes had been determined, the whole undertaking was to have been converted into a new company with a share capital of £5,000,000. This event, however, never took place. Although the briquettes which were produced were very satisfactory, both for firing and for gas production, and ammonium sulphate is said to have been obtained in satisfactory yields, it has not proved possible to make the process economically sound. The Dumfries Moor Works at Ironhurst closed in 1916–17 after a capital of £506,283 had been reduced to £2,725.[3]

A Government Commission was formed in 1917 to investigate the Irish peat bogs.[4] The peat bogs of Ireland, in which country about 5,500,000 tons of peat are used annually, cover more than one-seventh of the total area of the island—namely, 12,150 sq. km. out of about 84,000 sq. km. About three-sevenths of these bogs are situated in mountainous districts and yield peat which contains less ash and has a higher calorific value. The total peat reserves in Ireland are estimated at more than 100,000,000 tons; the next largest peat bogs are those in Scotland, whilst in England they are

[1] *Chem. Ind.*, 1913, p. 247.
[2] *Ibid.*, 1913, p. 219.
[3] *Ibid.*, 1917, p. 101.
[4] *J. Soc. Chem. Ind.*, 1920 (39), 213.

comparatively small in number. In 1918 there was founded the Osmosis Co., Ltd., London, with a capital of £20,000, in order to acquire from the Public Trustee and the Board of Trade, by virtue of the legislation introduced during the War, compulsory rights for the British Patent 10,024/1907 and about 40 further patents of the Elektro-osmose A.G. (Graf Schwerin-Gesellschaft). The Elektro-osmosis process of dehydrating peat plays an important part in the industry.[1]

The Scottish oil shale industry, which was very important even before the War, developed to an astounding degree under the influence of the diminished supply of raw materials since 1914, as is shown by the following short summary :—

Products.	1871 (51 Works).	1893 (13 Works).	1916 (6 Works).
Oil shale, treated (tons)	800,000	1,948,000	3,500,000
Crude oil (million litres)	113·5	241·1	365·5
Burning oil (million litres)	51·1	92·9	181·3
Lubricating oil (million litres)	11·4	39·8	49·9
Paraffin wax (pounds)	26,332	86,850	124,850
Crude ammonium sulphate (tons)	2,350	28,[illegible]	59,400 (purified 57,988 tons.)

The prices of the products also increased :—

	1871.	1893.	1916.
Illuminating oil (per gallon)	17*d.*	5*d.*	18*d.*
Crude oil (per ton)	£19·10	£5	£28
Paraffin wax (per pound)	10*d.*	5*d.*	6·5*d.*
Ammonium sulphate (per ton)	£19·10	£9·15	£15

The production of ammonium sulphate was 54,864 tons in 1910 and 62,207 tons in 1912. In 1917 3,117,658 tons of oil shale, valued at £1,280,007, and in 1918 3,080,867 tons, valued at £1,528,584, were mined. The average yields were about 110 tons of crude tar, 19·8 litres of oil, and 20 kg. of ammonium sulphate per ton of shale. In 1916–17 a special committee was formed in order to consider how the production could rapidly be raised. In 1918 the shale oil companies

[1] *Zeitsch. f. Elektrotechnik*, 1913, p. 739.

of Scotland—namely, Broxburn, Oakbank, Pumpherstone and Youngs companies—united to form the Scottish Oil Agency, Ltd., of Glasgow, with £100,000 share capital, for the joint sale of their products.

On the English chemical market the year 1914 was distinguished by very low prices for ammonium sulphate, such as had not occurred since 1898 or 1901; these dropped to a minimum of £10 6*s.* 3*d.* per ton in September, 1914. This corresponds to 21·07 marks per 100 kg. at pre-war exchange rates, as compared with 27·56 marks in 1911. The disappearance of Germany and Belgium from the export market caused a gradual price increase after October, 1914, which finally attained a maximum of £12 2*s.* 6*d.* f.o.b. Hull. At the outbreak of War stocks had accumulated on account of shipping difficulties and diminished demand. Conditions only improved gradually. There were 55,000 tons in stock at the end of 1914, and 26,000 tons at the end of 1915. In June, 1915, the price of 25 per cent. ammonium sulphate in London was £13 2*s.* 6*d.* to £13 10*s.* per ton, and in Hull, for 24 per cent. quality, £13 15*s.* to £13 16*s.* 3*d.*, in Liverpool £13 17*s.* 6*d.* to £14, and in Leeds in sacks, £14 2*s.* 6*d.* per ton. In 1917 the price at Liverpool had risen to £15 15*s.* The price remained fairly uniform during 1918, and rose to £16 15*s.* at the commencement of 1919. During the course of 1919 the Board of Agriculture arranged with the manufacturers for revised maximum prices for domestic deliveries of ammonium sulphate from October, 1919, to May, 1920. The prices agreed to were considerably higher, as the assistance given to producers by the Government during the War had been withdrawn, and the new prices had also to allow for the increased cost of coal, raw material and wages. The manufacturers' profits are described as moderate. The prices are based on quantities of not less than 2 tons, carriage free at the nearest railway station to the purchaser, with a small discount for dealers and so forth. The net cash price per ton in sacks was £20 10*s.* for October, 1919, and rose to £22 for March, April and May, 1920. These prices are based on an ammonia content of 24·5 per cent., and rise for each further $\frac{1}{4}$ per cent. NH_3 by 4*s.* per ton, and by a further 5*s.* per ton if a guarantee is given that the content of free acid shall not be greater than 0·25 per cent. When the ammonia contents are less, the prices are diminished by 4*s.* per 0·25 per cent. of NH_3 per ton. For deliveries under 2 tons, small additional charges are provided for.[1]

Until the end of 1919 export prices were from £21 10*s.* to £32 per ton, according to destination. There was a good demand. Export licenses were necessary. A maximum price agreement was con-

[1] *Chem. Ind.*, 15th September, 1919.

cluded in 1920 on the following terms, based on 2 cwt. sacks of a salt containing 24·75 per cent. by weight of NH_3 for internal consumption. For quantities over 4 tons, delivered free at the railway station of the purchaser, and including dealer's profit, the net cash prices per ton were :—

	£	*s.*
June, 1920	23	10
July, 1920	23	10
August, 1920	24	0
September, 1920	24	10
October, 1920	25	0
November, 1920	25	10
December, 1920	26	10
January, 1921	26	10
February, 1921	27	0
March–May, 1921	27	10

The prices for sulphate which contains more ammonia and less than 0·025 per cent. of free acid, or which is specially ground, are higher by 5*s.* 6*d.* to 7*s.* 6*d.* respectively per $\frac{1}{4}$ per cent. of NH_3 per ton of salt. The export prices were £30 per ton in February, 1920, £43 in March and April for the Colonies, and £30 to £35, and £50 to £55 respectively, for other places abroad. By the middle of 1921 they had dropped to £12 per ton. There has recently been an increasing demand in England for a prohibition of export of fertilisers.[1] It seems doubtful whether any such measure could be extended to ammonium sulphate, as England depends on the export of this product. English industrial circles hope to achieve the manufacture of a product which is absolutely unchanged by storage, by reducing the quantity of free acid.

Prices for Chile nitrate were very high during the War, in consequence of high freight charges, which amounted to £5 to £5 10*s.* per ton, even in 1919 (see under "Chile Nitrate"), but the price of nitrate gradually dropped to £24 5*s.* per ton for ordinary, and £24 15*s.* for refined nitrate by the middle of 1920. The new central sales office of the Chilean mines was forced to lower prices, as the demand was very small and stocks steadily increased. The surplus stocks of the British Ministry of Munitions were offered to farmers in 1919 at £20 per ton.

On the London chemical market on July 27th, 1920, ammonium carbonate was offered at 7½*d.* per lb., best quality ammonium chloride at £5 10*s.*, second quality at £5 5*s.*, and ground at £5 15*s.* per 100 kg. ; refined English potassium nitrate was sold at £3 17*s.* to £3 19*s.* per 100 kg., and 10 per cent. (?) Bengal saltpetre at £2 8*s.* per 100 kg.

[1] *Metallborse*, 1920, p. 1198.

During the War the area under grain in England increased, whilst the meadows and grass land decreased correspondingly:—

	Pre-War. Sq. km.		Post-War. Sq. km.
Land under wheat and so forth .	54,270	..	68,850
Meadows and grassland . .	134,865	..	120,285

In 1913 English agriculturists utilised about:—

100,000 tons of ammonium sulphate = 20,000 tons N.
80,000 tons of Chile nitrate = 12,480 tons N.

Total . . . . 32,480 tons N.

At that date about 30,670 sq. km. were under wheat, rye, barley, oats and potatoes. According to Sir Charles Fielding, 194,400 sq. km. would suffice to supply the total demands of England for foodstuffs, provided that the use of ammonium sulphate or Chile nitrate was increased by about 300,000 tons—that is, by about 50,000 to 55,000 tons of nitrogen—the use of superphosphate by 900,000 tons, and the use of basic slag by about 1·2 million tons annually. This estimate appears to be extraordinarily low when compared with German conditions. The German area of cultivated land was about 260,152 sq. km. in 1913, and at that time at least 210,000 to 220,000 tons of nitrogen were used on this land in the form of fertilisers. In 1918 a commission of Government representatives, industrialists and agriculturalists decided most emphatically that intensive agriculture and a corresponding utilisation of fertilisers in England must at all costs be ensured.

In March, 1917, England produced 28 times as much explosives as in March, 1915.[1] The carbide imports into Great Britain in 1915 and 1916 were as follows in tons (round figures):—

	1915		1916
From Sweden . .	4,000	..	2,200
„ Norway . .	18,000	..	17,000
„ Italy . . .	1,100	..	800
„ Canada . .	1,900	..	4,000
Total . . .	24,000	..	26,000

The average quantity of Chile nitrate used annually in England during the last few years before the War was about 120,000 tons, of

[1] *Chem. Ztg.*, 1918, p. 1.

which over 80,000 tons were used agriculturally. Thereafter the total imports of sodium nitrate in tons were :—

1915	131,520[1]
1916	20,896[2]
1917	1,680
1918	300
1919	24,485

The exports of potassium nitrate refined in Britain, in round tons, were :—

1918	820
1919	2,800

The imports of this product in 1916 were 21,000 tons, and in 1917, 19,000 tons.

Supplement, 1921–1924

In this country the main feature remains as hitherto the production of by-product ammonia from the distillation of coal. It is true that the coal production dropped from 292,080,000 tons in 1913 to 254,880,000 tons in 1922, and that the total coke production only amounted to barely one-third of the pre-war production in 1921 and about two-thirds in 1922. In 1920 there were 92 plants for the production of concentrated ammonia liquor from by-product ammonia and 631 producing ammonium sulphate. The production of ammonium sulphate in 1920 was :—

	Tons.
From gas works	176,196
From blast furnaces	10,441
From shale distilleries	54,290
From coke ovens	157,908
From gas producers, etc.	20,046
Total	418,881

The production of ammonium sulphate was 432,551 tons in 1918 and 397,513 tons in 1919. In 1922 133,373 tons of ammonium sulphate were produced by 796 gasworks. The exports of ammonium sulphate from Great Britain, which had held the first place in 1913 with 328,000 tons, dropped in 1922 to 148,000 tons (*Metallbörse*, **1923**, 1127 ; *Chem. Ztg.*, **1922**, 47, 691 ; *Chem. Ind.*, **1923**, 514, 614).

New coke ovens were being erected or had started production in 1923 (Pelton). The number of pounds of nitrogen applied in the form of manure per acre is in Germany 10·3, in France 4·5, in

[1] 129,458 tons from Chile ; 2,039 tons from Norway.
[2] 20,807 tons from Chile ; 11 tons from Norway.

England 2·01. Synthetic Ammonia and Nitrates, Ltd., joined the Ammonium Sulphate Federation in 1922. Wet Carbonising, Ltd., was finally liquidated in 1921.

The production of synthetic ammonia is at the moment still unimportant. The experimental plant of Synthetic Ammonia and Nitrates, Ltd., at Runcorn has been working uninterruptedly since the end of 1921 with a production of 1 ton of ammonia per day. The Billingham Works are expected to commence production in 1923–24 on behalf of Brunner Mond & Co., Ltd. They are to produce ammonia synthetically by a process similar to that of Haber. A production is expected of 300 tons of ammonia per twenty-four hours. Maxted's alleged thermic process has been condemned by German experts (*Chem. Ztg.*, **1924**, 73). A process which was announced in 1921 by F. W. Bowman, the President of the British Ammonium Co., Ltd., London, of producing ammonia synthetically in the absence of high pressure or high temperature has not been heard of since.

The Cumberland Coal Power and Chemical Co., Ltd., acquired licences for all the Claude processes, and the Tully Gas Plants, Ltd., of Newark-on-Trent, delivered two Tully gas producers for the production of 50,000 cu. m. of gas rich in hydrogen per twenty-four hours for use in Japanese Claude plants.

The British Cyanide Company successfully carried out experiments on the direct fixation of atmospheric nitrogen. In November, 1922, they completed the first plant of this kind, commenced production, and further works are to be erected (*Chem. Ind.*, **1923**, 236; *Metallbörse*, **1924**, 163).

CHAPTER X

The Nitrogen Industry in the Remaining European Countries

Belgium.—The first attempts to oxidise ammonia by the Ostwald platinum contact process were carried out in Belgium in the plant erected by Duché at Vilvorde in 1912–13, the ammonia being produced from calcium cyanamide from Odda, in Norway. It has already been mentioned that the results of these experiments were unfavourable, and that the whole plant was acquired by the English Nitrogen Products Co., Ltd., and Nitrogen Fertilisers Co., Ltd., in London. In September, 1914, the plant fell into the hands of the advancing German forces. In 1918–19 it was valued in the books of the Nitrogen Products Company at £138,100. The German Government paid £270,000 in compensation for damages.

Before the War Belgium produced about 40,000 tons of ammonium sulphate per annum. Certain of its works were associated before 1914 with the German Ammonia Sales Association (Deutsche Ammoniak V.V.). The coal production in 1913 was 22,846,000 tons, and the coke production 3,816,000 tons.

In 1919 Belgium concluded a three years' agreement with the Chile nitrate works for annual deliveries of 300,000 tons of nitrate. Its imports in 1913 were 304,136 tons.

In September, 1919, on the Antwerp market, nitrate was sold at 123 fr. per 100 kg., for spring deliveries; in 1920 150 fr., in May 155 fr., in July, 1920, 103 fr. or 115 fr. for spring delivery in 1921. Prices for ammonium sulphate were 170 fr. per 100 kg. in September, 1919, and 150 fr. in July, 1920. The price of ammonium carbonate was 400 to 410 fr. per 100 kg. in July, 1920, and that of ammonium chloride 300 to 350 fr. per 100 kg. The price of potassium cyanide in May, 1920, was 850 fr. per 100 kg., and that of sodium cyanide 810 fr. per 100 kg.

Italy.—The power question is of special importance in Italy, as there is absolutely no domestic coal. The normal peace requirements for coal were 12,000,000 tons. During the War, successful efforts were made to increase the production of lignite considerably. In 1913 the output of lignite was 664,000 tons. Now, however, about 1,500,000 tons are obtained annually, and it is hoped gradually

to increase this quantity to 3,000,000 tons. The development of water powers, which is being actively carried out, is a longer process. There is also a promising field in the exploitation of peat, which has been greatly assisted by the General Commission for Fuel with assistance by private enterprise, and by the investigation of the large peat moors of Sondrio and Lucca. In 1916 there were 40 firms which were active in connection with peat utilisation; in 1917 these had increased to 108, and on June 1st, 1918, to 149; 67,000 tons of peat were obtained in 1910, and 150,000 tons in 1917; the output for 1918 is estimated at 300,000 tons. The Italian military authorities have also interested themselves in the production of peat. Peat is also used as a fertiliser in Italy. The Mond gas process is utilised by the Società per l'Utilizzazione dei Combustibili Italiana, of Milan and Pontedera, which treats 90 tons of coal daily, and supplies 9,000 h.p. This company has gasified peat for thirteen to fourteen years, after gasification experiments carried out at Winnington in England, at the instigation of Frank and Caro, had demonstrated the suitability of the raw material. On the average, the Italian peat contained 40 per cent. of water. Its composition when dry was as follows :—

15·20 per cent ash.
43·80 per cent. volatile matter.
1·62 per cent. nitrogen.
56·30 per cent. total carbon.
34·20 per cent. fixed carbon.
5,620 calories, cal. value.

In Winnington, 650 tons were treated in all, and produced, per ton of dry material, 55 kg. of ammonium sulphate, and 1,780 cu. m. of power gas of 1,360 cals., which correspond to 480 effective horse-power hours in a gas engine. The nitrogen yield was about 70 per cent.; not the slightest difficulties were met with in purifying the gas, which contains 0·016 gms. of tar per cu. metre; the hydrogen contents of the gas varied by about ½ per cent. only, and calculation showed that the horse-power of electric energy obtained would cost less than ½ pfg. (0·06*d.*) apart from the sale of ammonium sulphate.

The Italian Company exploits the peat which has formed in the former lake at Bientina. Its power station is at Orentano, 36 miles from Pontedera. Up to 1913 the peat gasification plant supplied about 2,000 kw. annually; it was to have been extended in 1913–14.

The ammonium sulphate works "Ammonia" of Milan, which had a share capital of 10,000,000 lire, changed their name in 1919 to Società Italiana per le Ligniti e Torbe.

The Commission for Chemical Industry approached the Ministry of Trade in 1918 to the effect that in all future applications for concessions for the utilisation of water powers, those should have the preference which proposed to utilise a considerable portion of the power for the production of nitrogen compounds. At the meeting of the Association of Italian Joint-Stock Companies in Rome in 1918, Signor Nitti emphasised the necessity for the foundation of a large Bank for financing export trade and installations utilising Italian water-powers. The Società Generale Elettrica dell' Adamello has a capital of 100,000,000 lire. A large water-power development was planned in 1918 at Domaso on the Lido. For this purpose a dam was to be constructed near the bridge of Dagri 700 m. above sea level, in order to carry the river water through a canal along the mountain side to below the village of Caino, 300 m. above sea level.

As Italy is mainly dependent on England for its coal supply, there has been a latent coal crisis since the Italo-Turkish War of 1913, as the suppliers at that time cancelled their contracts on the grounds of the war clause.

Previously to 1913 the price of English gas coal was 25 to 35 lire per ton free at the gas works. It rose to 50 to 60 lire per ton in July, 1914, and then rapidly rose further. In 1916 the price was 200 to 220 lire per ton.[1] Italy therefore turned to North America for coal supplies. Many gas works closed during the War. In 1916 the price of lighting gas had already increased to three to four times its former price, and public illumination was very much reduced. The whole of the tar production was requisitioned for military purposes at a maximum price of 45 lire per ton. As the distilling plant at Borgo san Donino was too small to cope with the whole of the supplies, the reservation of all these by the State was in part countermanded. All gas works with a production of more than 1,000,000 cu. m. per year were obliged to erect a plant for the recovery of benzole and toluole, facilities being given for writing off this plant in five years. In 1916 the price of coke was twice to two and a half times the pre-War price, and the price of ammonium sulphate had doubled. In one way and another the financial position of the Italian gas works at that time may be described as exceedingly bad.

During the War Italy endeavoured with remarkable success to increase its chemical industry, which had been very unimportant previously. In 1920, of a total capital of 11,782,905,381 lire, belonging to 4,414 joint-stock companies, the chemical industry accounted for 174,319,000 lire, belonging to eighty-three under-

[1] *Journal f. Gasbel.*, 1916, p. 426.

takings. In addition there were 30 wholesale merchants, with a capital of 38,848,000 lire. Before the War the annual value of the production of the chemical industry was about 200,000,000 lire, of which the main portion was due to the manufacture of superphosphate in 87 works, of which 35 of the most important were united in a trust.[1] The imports of crude phosphate into Italy in tons were:—

1905	240,100
1912	466,100
1913	259,800
1914	514,000

In 1915 almost 1,000,000 tons of superphosphate were obtained from imported phosphates, so that only a very small fraction remained to be imported. The imports of superphosphate in tons were :—

	Production.	Imports.	Consumption.
1905	480,000	30,000	510,000
1912	1,050,200	37,000	1,087,200
1913	972,500	74,700	1,040,000
1914	925,000	38,200	960,000

The production of superphosphate necessitated large quantities of sulphuric acid which could be covered from internal resources. In 1917 500,000 tons of pyrites were mined for the manufacture of sulphuric acid ; in addition, the production of sulphur was about 500,000 tons (in 1913 it was 394,000 tons, of which 345,000 tons were produced in Sicily). The production of sulphuric acid was as follows :

Year	Tons.
1905	302,100
1912	634,521
1915	625,943

Sulphuric acid was produced from sulphur by the Colla e Concimi, of Portici and Barletta. Fuming sulphuric acid for the manufacture of explosives was produced in plants at Bolognano, Avigliano and Cengio. The production of copper sulphate (26,212 tons in 1905 ; 41,272 tons in 1916), of Turkey red oil for the textile industry, and of tartaric and citric acids, was fairly important. In Western Liguria, in the neighbourhood of Pavona and Albenga, the number of chemical works is particularly large.

[1] See also "Verband der italienischen Superphosphatwerke und Fabriken Chemischer Produkte," *Zeitsch. f. angew. Chem.*, 1920, ii., 438.

Before the War the total import of chemical products reached an annual value of 180,000,000 lire. The development of the chemical industry was generally rendered extremely difficult by the dearth of suitable apparatus and machinery, and also by the absence of technically educated chemists and engineers. The electrolytic chlorine industry has grown considerably. The production of benzene, toluene, phenol, naphthalene, dye-stuffs, carbon disulphide, electric steel, essential oils, and so forth has once more been taken in hand and improved.

The first atmospheric nitrogen works in Italy was that of the Società Italiana per la Fabbricazione di Prodotti Azotati, which was formed by the Cyanidgesellschaft m.b.H. of Berlin and by the Deutsche Bank. Their works at Piano d'Orta started manufacture in 1905. This was the first installation of the Frank-Caro cyanamide process on a large industrial scale, and it was mainly there that it was developed. The Piano d'Orta works utilises the water power of the Pescara in the Abruzzi. The productive capacity, which was originally only 4,000 tons of cyanamide, was later increased to 14,000 tons. In 1918 the capital of the Società Italiana per la Fabbricazione di Prodotti Azotati was increased from 6·6 to 9·9 million lire. The Società Italiana per il Carburo di Calcio at Terni (Umbria) uses the three large falls of the Velino, with a total fall of 200 m. at the confluence of this river with the Nera, which escapes from the Roman Apennines 7 km. downstream, near Terni. The output capacity for cyanamide in 1912–13 is given at 24,000 tons. The Società Piemontese per la Fabbricazione del Carburo di Calcio e Prodotti Affini at Saint Marcel in the valley of the Dora Baltea, 11 km. east of Aosta, has a capital of 2,000,000 lire. This company operates two carbide furnaces of 1,000 and 2,000 kw., with water power from the Dora Baltea, and produces 2,400 tons of carbide annually. The possible production of cyanamide for 1912-13 was estimated at 3,500 tons. The limestone comes from the quarries at Meana di Susa. The Società Italiana Prodotti Esplodenti, of Milan, produces ammonium nitrate and cyanide products at Vado Ligure, and nitric acid, explosives, and so forth at Cengio.

The large water-powers on the southern slopes of the Alps were exploited for carbide manufacture at an early date in the valley of Aosta, the province of Brescia and so forth. The largest Italian works belong to the Società Italiana per il Carburo di Calcio already referred to, and are established at Collestate and Papignano, near Terni. The total carbide production of Italy in 1914 was about 65,000 tons, and employed 50,000 h.p.; about 10,000 tons were exported. In 1913 more than 50,000 tons were produced, and in

that year 11,037 tons were exported ; in 1916 the exports were 4,215 tons. A special product is obtained by coating with glucose. There is a tax on the consumption of carbide. The carbide industry was greatly stimulated by the War.

In 1914 about 4,700 tons of calcium cyanamide were converted into ammonium sulphate. In 1917 the Società per lo Sviluppo Della Cianamide e di Altri Prodotti Chimici was founded at Rome, with a capital of 12·5 million lire, in which foreign cyanamide works were interested ; its business headquarters are in Turin. It is known from the reports of the English Nitrogen Products and Carbide Co., Ltd., that an Italian firm was erecting a plant for the company's catalytic process of oxidising ammonia and for their ammonium nitrate process in 1916–17.

The Officine Elettrochimiche Dott. Rossi, in Legnano and Vergiate, utilises the Pauling process, and produced in 1913 1,200 tons of atmospheric nitric acid of 36° to 42° Bé. in eighteen furnaces, each absorbing 500 k.w. As no ammonium nitrate had been produced in Italy before the War, at the outbreak of war the "Rossi" Electro-Chemical Works at Legnano took up this manufacture for the Government. In order to increase the output of atmospheric nitric acid, they purchased the Anio Power Station at Ponte Mammolo, near Rome, in 1916. After being considerably extended, this was opened in 1917 for the production of ammonium nitrate and other electro-chemical products. At the same time the parent company increased its share capital from 1,000,000 to 8,000,000 lire, and in 1918 the capital was again raised to 20,000,000 lire. In 1913 the works also produced 570 tons of potassium chlorate and 160 tons of potassium nitrate. In Domodossola a works was started in 1920–21 with an output capacity of 10,000 tons of cyanamide.[1]

The Società Prodotti Chimici Colla e Concimi, of Rome, increased its capital in 1918 from 12,000,000 lire to 20,000,000 lire, and entered into close co-operation with the Società Industria Italiana, which is interested in the production of atmospheric nitric acid. Agreements were also entered into with the Electrode Factory of the Società Italiana Carboni Elettrici. The largest producer of sulphuric and nitric acids was the Unione Concimi, of Milan, which extended its works greatly during the War. Its capital in 1916 was 35,000,000 lire, in 1918 40,000,000 lire, and in 1919 50,000,000 lire.

The Unione Italiana fra Consumatori e Fabbricanti di Concimi e Prodotti Chimici, which is a combination of the principal producers of superphosphate, with a capital of 70,000,000 lire, amalgamated in 1920 with the abovementioned Società Prodotti

[1] *Chem. Ztg.*, 1921, p. 212.

Chimici Colla e Concimi of Rome. It is proposed that it should also absorb the united companies of the Montecatini Mines in Milan, which propose to increase their capital for this purpose from 140,000,000 to 200,000,000 lire.[1] The Unione has an extensive programme for the erection of a large fertiliser works covering 180,000 sq. m. for the production of sulphuric acid, superphosphate and so forth, which is to adjoin the new industrial harbour which is to be built at Venice with a front 400 m. long on the Northern Commercial Canal.

In 1916 the Anonima Fabbricca Italiana di Solfato Ammoniaco, of Milan, increased its capital from 1,100,000 to 5,000,000 lire. Amongst the newest company foundations and extensions one may also mention the Società Anonima Industrie Chimiche Agricole, of Rome, the Società Agraria di Domodossola of Rome, the Industrie Chimiche Conti, of Florence, the Fabbrica Concimi Chimici del Sannino, and the Ossinitrica, of Genoa. The works at Nogaro of the Unione Concimi were completely destroyed during the War.

There was very little manufacture of atmospheric nitric acid previously to 1914; there were, in 1911, only a few small experimental works.[2] It was reported from Rome in June, 1920, that the Professor of Chemistry, L. Casale, had succeeded, after experiments extending over many years, in producing synthetic ammonia from air and water without the use of coal. "The machinery to be utilised for this purpose is said to work automatically without attention or labour, and forces a mixture of nitrogen and hydrogen through specially constructed tubes at a pressure of 250 atmospheres; in these tubes the gases are converted into pure ammonia, which costs almost nothing. The invention is already being exploited by a company which has acquired important water powers for the purpose. It is estimated that the works will supply sufficient ammonia, not only for Italian consumers, but also for export." The final success of this modified Haber-Bosch process is still awaited. A syndicate is also stated to have been formed in Rome in 1920 to promote the use of nitrogen instead of benzole for driving motors. Only slight alterations of the carburettor are said to be necessary. According to the experiments which have so far been carried out,[3] the costs for fuel for a 25 to 30 h.p. car, driven a distance of 60 km. during one hour, are 53 centimes. During the War the manufacture of carbide and

[1] *Chem. Ztg.*, 1920, p. 588.

[2] *Ibid.*, 1911, p. 1185. A capital of 25,000,000 lire is to be devoted to the erection of a calcium nitrate works in South Tyrol (Etsch Works at Meran), with the assistance of the Elektrobank of Zürich; the proposed annual production is to be 5,600 tons of 16 per cent. calcium nitrate.

[3] *Zeitsch. f. angew. Chem.*, 1920, ii., 131.

cyanamide was under Government control. The average production of carbide per month in 1918 and 1919 was 4,759,000 lb.[1] "The cyanamide works at present active in Italy are able to produce 12,346,000 lb. of cyanamide monthly. The average production during the years 1918 and 1919 was, however, only 3,968,300 lb. Of this quantity, 3,174,600 lb. were sold directly, the remainder being employed for the production of ammonium sulphate. Neither calcium carbide nor cyanamide have been imported in quantity during the last two years. In order to satisfy the large demand for ammonium sulphate which had been almost completely supplied in Italy before the War by imports from abroad, the inland production was greatly increased by utilising the by-products of the gas works and coke ovens. In 1914 the internal production of ammonium sulphate was 2,535,000 lb. In 1918, however, it was already 7,275,000 lb., of which 2,622,000 lb. were produced in gas works, 880,000 lb. from coke ovens, 660,000 lb. from cyanamide plants, and 113,000 lb. from peat distillation plants. The imports of ammonium sulphate dropped very considerably from 48,000,000 lb. in 1913, to 5,500,000 lb. in 1918–19. It is possible that when normal conditions are restored, imports of ammonium sulphate will rise again, but the high figure of 1913 will probably never be attained."

Before the War the Italian consumption of artificial fertilisers per hectare of cultivated land was :—

	Kg.
Phosphate	52·65
Potash	3·80
Nitrogen	0·65
Total	60·00

In 1913 there were imported : 1,586 tons of potash ; 7,061 tons of potassium chloride ; 485 tons of potassium nitrate ; and 9,454 tons of potassium sulphate. The imports of Chile nitrate were :—

Year.	Tons.
1913	67,417
1914	58,849
1915	71,729
1916	85,649

In 1913, 1,600 tons of potassium nitrate were produced. The production of calcium cyanamide was :—

Year.	Tons.
1912	10,304
1913	14,982
1914	15,556
1915	25,292

[1] See *Metallborse*, 1920.

11,800 tons of carbide were nitrogenated in 1914. The actual output capacity of the Italian cyanamide works is now about 60,000 to 70,000 tons, whereas, in 1913–14, it was about 45,000 tons. In Milan an " Institute for the Promotion of Fertiliser Trials " has been established.

In 1913, 13,010 tons of nitric acid were produced, and 600 tons were imported. During the War the production was greatly increased, as the atmospheric nitric acid industry developed very considerably. The Dinamitificio Cengio is mainly interested. In 1913 the Rossi works only produced 1,200 tons of acid of about 40° Bé. It was not possible to obtain reliable statistics on the amounts of nitric acid and ammonium nitrate which are now manufactured.

Oxygen is produced at various works by the Linde, Claude and Pictet processes. Aluminium nitride is said to be produced in small quantities. In 1918 coal mining was made a State monopoly.

The Italian requirements for fertilisers are stated officially to be as follows :—

100,000 tons of Chile nitrate (imports from Chile in 1913, 67,417 tons).
25,000 tons of ammonium sulphate.
25,000 tons of potash fertilisers.
600,000 tons of phosphates.
100,000 tons of basic slag.

During part of the War there was a serious deficiency of fertilisers. At the commencement of 1919 steps were at last taken by the Government to supply the fertiliser works with both domestic and foreign raw materials and to acquire and distribute the nitrates which were released by the military authorities. The supply of phosphates was very difficult, in so far as France restricted exports of phosphorite from Algiers and Tunis at the commencement of 1919. The sudden and unexpected announcement of this French regulation caused much bad blood in Italy, as the amount which was released was to be smaller than that which had been imported from Algiers and Tunis during the War, and supplied far less than one-third of the Italian peace requirements.

Spain.—Spain is very rich in water-power, and the electrical development of the country increased very rapidly during the War, before which time promising beginnings had already been made. The nine large companies which supply Spain with electric power utilise about 500,000 h.p. of the 5,000,000 h.p. which is available. The A.E.G. and Siemens groups predominate among the German undertakings in Spain. Spain now produces about 15,000 tons of

carbide in thirteen electro-chemical works. In 1916 they produced 34,522,000 lb. of carbide and 3,285,000 lb. of ammonium sulphate. In 1913 neither carbide nor ammonium sulphate was produced.

In spite of the value of the mineral resources of all kinds, including ores, coal, lignite, salt and so forth, the chemical industry of Spain is only very slightly developed. Few new sulphuric acid works were erected during the War, but the old works were largely extended. The exports to France were 36 tons in 1914, 3,000 tons in 1915, and almost 7,000 tons in 1916. There are important coal deposits in Asturia and in the valleys of Ujo, Puertollano, Valencia, Bojador, Utrillos, Figols and other places. The deposits at Valencia consist of anthracite. There are large lignite deposits in the Pyrenees. Good transport facilities are lacking almost everywhere. The total coal production rose from 2,583,000 tons in 1900 to 3,783,000 tons in 1913. There are very large oil-shale deposits in Castile and Andalusia, but they are rather poor, yielding 6 to 12 per cent. of oil. They are only being exploited on a modest scale. In 1918 there were about nineteen purely Spanish undertakings concerned with chemical industry; these had a joint nominal capital of 53,695,000 pes., and an actual paid up capital of 43,668,000 pes. The S.A. Minera de Peñarroya and the Union Española de Fabricas de Abonos, with works at Malaga, Alicante, Valencia and Seville, works with French capital, and the "Superfosfatos" is English. The production of the former works was 167,000 tons of superphosphate in 1913, 66,000 tons of sulphuric acid in 1917, and 84,500 tons of superphosphate in the same year. The Union Resinera Española, with a capital of 20,000,000 pes., is devoted to resin products, and has numerous works and branch establishments. The development of various valuable phosphorite deposits has so far been hampered by deficient railway communications, but the domestic production has sufficed to supply home demands. The production of potash salts from the mines of the provinces of Barcelona and Lerida, in connection with which the German potash syndicate had already acquired some influence before the War, progressed very little, which is much to be regretted from the point of view of fertiliser supplies in Spain. In 1913, 23,025 tons of chemical products were imported into Spain, mostly from Germany, France and England. During the War period the United States, France and England endeavoured to acquire a predominant position in the Spanish chemical market. German influence is now once more increasing rapidly.

In 1919 three works for the production of atmospheric nitric acid were being erected—one at Viana, supplied with 8,000 h.p. of hydro-

electric power; another at Lerida, for which 25,000 h.p. are at present available, later to be increased to 75,000 h.p.; and the third in Corcubion. In 1913 the Norsk-Hydro had already granted a licence, for 1,000,000 fr. and an annual payment to a financial group headed by the Banco de Castilla, for the use of a process which the group were to develop in Spain and Portugal.[1] For this purpose the Sociedad Ibérica del Azoe was founded. When, however, the Schönherr furnace was found to be more efficient than the Birkeland-Eyde process, it was decided to work with the former.[2]

The works at Viana (Navarre) utilise a waterfall of the Ebro. They are being built and operated by the Compania Navarra de Abonos Quimicos de Pamplona. The costs of the water-power development and electric plant were estimated at 5,000,000 pes., and of the works at 3,000,000 pes. During the War no calcium nitrate was produced at these works, as they were still unfinished in 1920. The Lerida Works are in a still earlier state of construction. With a power utilisation of 35,000 h.p. the output of atmospheric nitric acid in Spain should be increased in the next few years to about 15,000 tons of concentrated nitric acid.

The Sociedad Electrometalurgico del Astillero, of Santander, which was founded in 1913 with a capital of 20[illegible]0 pes., had temporarily to close their carbide works which were opened in January, 1914. Towards the end of 1919 important financiers from the Basque provinces of Navarre met at Pamplona to form a new company for the manufacture of chemical products, "La Biurdana," to utilise the surplus salt production of these provinces. It is proposed to obtain the necessary electric power for an electrolytic plant, for the decomposition of brine and so forth, by utilising a waterfall near Pamplona. The fixation of atmospheric nitrogen is also being considered. In 1920 the French Société des Produits Azotés obtained a concession from the Spanish Government for the erection of a cyanamide works with a capital of 1,500,000 fr. Sulphuric acid, phosphoric acid, and so forth, are also to be produced. It is rumoured that a new process for the production of cyanamide derivatives is to be installed.[3]

Before the War 1,150 tons of benzole were produced annually in four works. Since 1914 three new works and one extension have been added, so that to-day 2,200 tons of benzole can be obtained. The Siderúrgica del Mediterráneo is also about to erect a further plant of an annual output capacity of 600 tons.

[1] *Chem. Ztg.*, 1913, p. 1387.
[2] F. A. Bühler, *Chem. Ztg.*, 1913, p. 1509.
[3] *Chem. Ztg.*, 1920, p. 547.

Long before the War the Altos Hornos de Vizcaya were considering plans for recovering by-products from the gases of their six batteries of coke ovens. A German firm had been entrusted with the supply and construction of the plant, which was to have been finished by the end of 1914. Part payment had already been made, but the delivery of plant, which had meanwhile been completed, could not be made, as war had broken out. On account of the increasingly serious lack of benzole, the company decided to complete the plant with their own resources. They entrusted the completion of the project to the engineers Bollard, father and son, who were employed in their works at Barracaldo and Sestao. In November, 1918, the new works, which were planned for the production of benzole, naphthalene, heavy oils, ammonium sulphate and ammonium chloride, were started. The annual production of first quality benzene is about 700 tons, and that of naphthalene, about 140 tons. In spite of difficulties in the coal supply, Barracaldo and Sestao produce 300 tons of ammonium sulphate per annum, which could be increased to about 400 tons under more favourable conditions; 150 kg. per day of ammonium chloride can be produced. It is utilised in the works in the production of tin plate. At Barcelona, in the middle of 1919, the price of naphthalene was about 850 pes. per ton, ammonium sulphate 1,500 pes. per ton, and ammonium chloride 2 pes. per kg. In 1918 the price of ammonium sulphate was 2,000 pes. per ton.

In Spain fertilisers are mainly used in the cultivation of rice in the neighbourhood of Valencia. The annual requirements are 60,000 to 70,000 tons of ammonium sulphate. Before the War 100,000 tons of phosphate were imported from Florida and 200,000 tons from Algeria; the home production of phosphates amounted to from 16,000 to 18,000 tons of low grade product. The whole of the phosphate is converted into superphosphate. At the close of 1920 the following maximum prices were fixed by the Government: superphosphate containing 13 to 15 per cent. of P_2O_5, 16·00 pes. per 100 kg. at works; 15 to 17 per cent. quality, 19·00 pes.; 16 to 18 per cent. quality, 20·25 pes. The imports of Chile nitrate in 1913 were 35,235 tons; imports of ammonium sulphate about 203,000,000 lb. of which 55,000,000 lb. came from Germany and 117,000,000 lb. from England. In 1918 the imports of ammonium sulphate were only 270,584 lb.

At the close of July, 1920, when the German exchange was 692·50, the following prices were paid in Spain [1]:—

[1] *Metallbörse*, 1920, p. 1198.

	Per 100 kg.
Aqueous ammonia of commercial quality in carboys	170 pes.
Ammonia of first quality in carboys	220 ,,
Nitric acid, 40 degrees, best quality, colourless, in carboys	140 ,,
Ammonium sulphate, 20 to 21 per cent. N	130 ,, [1]
Chile nitrate, 15 to 16 per cent. N.	68 ,,

Portugal.—The erection of carbide furnaces in Portugal is being considered.[2]

Denmark.—There is so far no nitrogen fixation industry in Denmark, as the insufficient power resources of that country are not encouraging for the purpose. In 1919 a plan was considered of supplying Denmark with Norwegian electric power on a very large scale; this is perfectly feasible from a technical standpoint, by means of heavy cables and so forth.

Energetic attempts are being made to utilise the peat moors, which have an area of 3,000 sq. km. The number of mechanical installations for this purpose had increased from 57 in 1916 to 162 in 1917, and during the same interval the amount of air-dried, machine-made peat increased from 22,000 tons to 56,000 tons (= 168,000 cu. m.). In 1917–18 Government assistance was afforded to 225 works to the amount of 200,000 kr. At an average price of 18 kr. per cubic metre of peat the mechanically gained peat alone represents an output of 3,000,000 kr. According to other reports,[3] the total production of crude peat in Denmark in 1917 amounted to 9·5 million tons of the value of 27·5 million kr. Favourable results have been obtained by the utilisation of peat mixed with various other fuels in locomotives. In 1916–17 the Vestre Gas Works at Copenhagen commenced to admix their coal gas with peat gas. The gasification of a mixture of 70 per cent. coal, and 30 per cent. peat proved unsatisfactory, but, on the other hand, by filling the retort with 80 per cent. of coal and 20 per cent. of peat from the municipal moor at Viksö, good results were obtained. Mixtures of peat gas, coal gas, and water gas were also used, in view of the serious scarcity of coal. In 1917 a method of driving Diesel motors with peat gas in place of oil, which was difficult to obtain, was developed at the large shipbuilding yards and Diesel motor works, A.S. Burmeister and Wains at Copenhagen. On account of oil shortage a number of Danish communities have converted a portion of the motors in their electric power stations to work on this system.

[1] At close of 1920 90 pes. only.
[2] *Zeitsch. f. angew. Chem.*, 1920, ii., 108.
[3] *Chem. Ztg.*, 1918, p. 376.

Successful experiments have also been made by the Government on the production of peat charcoal by slow combustion. The charcoal which is so obtained is said to have a calorific value of 6,000 calories, and to be very suitable for use in forges. So far there are no peat gas generators in Denmark with facilities for recovery of ammonium sulphate and other by-products.

In 1918 a joint-stock company was in course of formation with a capital of 800,000 kr., which proposed to produce a high-grade fuel of 4,700 calories value by Malling's process from sea-weed, by compressing it into briquettes and drying rapidly at a high temperature. The sea-weed is found and gathered both on the Baltic and also in the Watten district on the North Sea. The production of such briquettes from sea-weed is said to be no more expensive or complicated than from dry peat.

In 1918 preliminary investigations for a project of manufacturing nitrate in Denmark began to assume a more definite form. Not only was such an installation proposed by the A.S. Christiansholms Fabriker, of Copenhagen, but a Government Commission nominated for the purpose received 80,000 kr. from the Danish Fertiliser Association for the erection of an experimental works, on condition that the working costs should be covered by the Government contribution. The Commission therefore petitioned the Government for a subsidy of 20,000 kr. per annum for three years. Preliminary investigations were carried out by Raaschou and Meyer at the Copenhagen Polytechnic. Such a plant has not yet been erected.

Compressed acetylene has been used considerably for driving vehicles, and acetylene lighting found a wide field during the War. All the carbide was imported from the northern countries.

The industry of compressed and liquefied gases is comparatively important in Denmark. In 1913, one works was producing carbon dioxide, and two hydrogen and oxygen; the total number employed was 30, and 435 tons of liquid carbon dioxide, 76·5 tons of oxygen (valued at 77,000 kr.), and 20·2 tons of hydrogen were produced. There were also imported 46·6 tons of carbon dioxide, and oxygen to the value of 39,000 kr. The Aktieselskabet Dansk Ilt-og Brintfabrik, of Copenhagen, produces oxygen and hydrogen by the Linde process. They had an explosion in March, 1915. They have a branch factory at Aarhus. There are several artificial ice works. The Jydsk Iltfabrik A.S, at Horsens, in Jutland, which manufactures oxygen, welding apparatus and auxiliaries, resumed operations in 1919.

The imports during 1918 and 1919 were as follows :—

	1918.	1919.
Coal. . . .	1·75 million tons	1·96 million tons
Crude phosphate .	—	35,698 tons
Superphosphate .	—	66,864 ,,
Nitrogenous fertilisers.	19,947 tons	36,588 ,,
Synthetic nitrate .	19·6 ,,	33·3 ,,
Chile nitrate . .	116 ,,	48,108 ,,
Kainite . . .	508 ,,	1,021 ,,
Other potash salts .	33,869 ,,	107,696 ,,
Potassium nitrate .	12·0 ,,	292 ,,

The total value of the imports of fertilisers was 78·3 million kr., and the value of exported fertilisers of Danish origin was 0·13 million kr., and of foreign origin 0·87 million kr. The annual consumption of carbide was 900 tons in 1913, and 2,200 tons in 1916.

In consequence of the absence of regular imports of Chile nitrate and nitric acid, the supply of Denmark with fertilisers has been difficult since 1914. There was therefore a good demand for calcium nitrate and calcium cyanamide from Sweden and Norway. Chile nitrate was supplied by the Danske Gödningskompagni and the Ostasiatisk Kompagni, of Copenhagen ; the latter firm has recently acquired a few Chilean nitrate deposits. In the summer of 1916, there was formed an agricultural organisation known as the "Dansk Andels-Gödningsforretning af 1916," which proposed to supply its members with sufficient quantities of Chile nitrate in 1917, but was unable to fulfil this promise completely in consequence of the political situation. The following maximum prices were fixed in November, 1916 : 37 kr. per 100 kg. when sold direct to the purchaser, exclusive of transport charges and of an additional charge of 0·50 kr. if bought from stock. In 1919 the Government granted an import licence for Chile nitrate to the A.S. Dansk Svovlsyre and Superfosfatfabrik, of Copenhagen, under the condition that their maximum sale price should be 55 kr. per 100 kg. gross, including sacks, f.o.r. or f.o.b. at port of entry, including 1 kr. profit for the broker. At the commencement of 1915 trading in ammonium sulphate and other artificial nitrogenous fertilisers was forbidden for a time until a general revision of the previous regulations had been effected.

Until the autumn of 1916, carbide was imported quite regularly from Sweden and Norway. When, however, the Norwegian works were partially transformed for the production of ferro-silicon, and Sweden also only supplied half as much as formerly, as the home consumption increased, the supply in Denmark, in which there are no carbide factories, became very poor. In order to meet the lack of lighting facilities, 10,000 tons of carbide would have been necessary in 1917, whereas, in the winter of 1917–18, only 400 to, at most,

1,200 tons were available. The price per kilo was formerly 0·30 kr.; in 1917, in the retail trade, it was at least 1·35 kr., and from June 26th, 1918, 1·27 to 1·40 kr. according to the amount; the wholesale houses sold to the retailers at 1·17 kr. per kilogram in drums. Since November 1st, 1917, carbide could only be sold to users on production of a special permit from the Fuel Control Board.

Iceland is richer in water powers than the Danish mother country. The Fosseaktieselskabet Island intends, in accordance with the proposal it made to the Iceland Government in 1917, to develop the Sog Falls, the outlet of the Thingvalla-Vata, 45 km. from Reykjavik, from which it intends to obtain 50,000 h.p., and to erect an atmospheric nitric acid works for supplying the agricultural interests of Iceland and Denmark. A railway is also to be built, and the southern portion of the island is to be supplied with cheap electric power. The capital is mainly Danish. The new company also controls proprietary or utilisation rights in several other waterfalls of Iceland, such as the Gullfos. The Norwegian-Icelandic Company "Titan," made detailed plans in 1918 for the development of the Thorsaa River.[1] Along the banks of this river six power stations are to be built, with an estimated output of 1,114,000 h.p. A portion of the power is to be supplied to Reykjavik. The construction of a railway to Reykjavik and the adjoining districts is also intended. Atmospheric nitric acid is to be produced on the spot. The Titan Company, in which the Norsk A.S. for Elektrokemisk Industri of Christiania is interested, increased its capital from 4,000,000 to 6,000,000 kr. in 1919; this company has great faith in the future of Iceland as an industrial country, which, however, could not develop its resources without external assistance. It remains to be seen to what extent the two neighbouring Icelandic companies, with plans which are similar in many cases with regard to the construction of railways, overland concessions and so forth, will work together. In 1920 the town of Reykjavik decided to construct an electric power station on the Ellidarelf for an output of 1,000 h.p. at a cost of 2,000,000 kr.

Netherlands.—A domestic nitrogen fixation industry has not yet been developed in the Netherlands, but the preliminaries for such a development are already there.

The effect of the War on the Dutch chemical industry was, like that of a protective tariff, and favoured development to an extraordinary degree. The supply of capital in the form of new shares in the chemical industry of Holland between September, 1915, and September, 1918, amounted to 15,623,000 gulden, as against

[1] Frank, "Technik u. Wirtschaft," 1919, p. 631.

20,000 gulden in the years 1912 and 1913. In the metal industry these values were respectively 32,132,000 gulden and 6,716,000 gulden. Under the circumstances, it is feared that when foreign competition is once more restored and when the War prices drop, a critical economic situation will arise. Various institutions have for their object the stimulation of the sale of domestic products; among these may be mentioned the fairs at Utrecht and elsewhere, the Maatschappij van Nijverheid and Bureau voor Handelsinlichtingen. The assistance of the Government to Dutch industry is not desired in the form of a protective tariff, but rather by the removal of obstructive influences, by the construction of canals, the establishment of chambers of commerce, energetic representation abroad, and so forth. The high exchange value of the gulden facilitated the competition of foreign imports on the Dutch market and simultaneously rendered Dutch exports more difficult. At the commencement of 1919 the Dutch producers of fertilisers were already complaining of the disadvantages of too large an import of Chile nitrate.

The nitrogen famine during the War was extremely serious. Before 1914 100,000 tons of Chile nitrate and 40,000 tons of ammonium sulphate were imported annually. During the War practically all that was available was the small home production of the gas works, amounting to about 4,000 tons of ammonium sulphate per annum. The coal production of Limburg was scarcely utilised for the production of coke and by-products. It increased from 1,873,000 tons in 1913 to 3,079,000 tons in 1917. The price in 1913 was 8 to 10 guldens per ton, and in 1917 16 to 20 guldens per ton. The supply of coal is a monopoly. In 1917–18 the first coke oven battery was commenced in Limburg, and was to produce, among other products, 135 tons of ammonium sulphate per month; and in 1919 a company was founded with a capital of 4,000,000 gulden in order to establish coke ovens on the Rotterdam canal, known as the Nieuwe Waterweg, which is a canalised branch of the Maas between Rotterdam and the North Sea. The Dutch Government is developing as far as possible the further extension of its coal mines and of transport arrangements for coal. It submitted to the Second Chamber in August, 1920, a credit advance for this purpose of more than 30,000,000 gulden. The peat moors, which have an area of 2,000 sq. km., have not yet been exploited chemically.

Even if the production of the Limburg coke ovens, which was unimportant in 1918, is included, only about 1·5 per cent. of the coal burnt in Holland in 1918 was utilised with recovery of by-products Through the lack of cattle food, the quantity of farmyard manure

also diminished noticeably, and in peace-time about 20,000 tons of nitrogen were lost annually in this form. In the circumstances, it was only natural that the Dutch Ministry of Trade should have submitted to it a whole series of plans for the erection of a national nitrogen works.

At a meeting of the "Landbouwbond" of Groningen, G. J. van Swaay, Professor at the Technical University of Delft and J. Verheijen, of Rosendaal, a member of the Directorate of the North Brabant Electric Supply Company, proposed the erection of a cyanamide works adjoining the central electric power station at Gertruidenberg. The annual production was to be 20,000 tons, and the cost was estimated at 750 gulden per ton. It would have to be reduced, however, to 390 gulden per ton, in order that the product might compete with Chile nitrate. If the Dutch Government took over the whole production for one year at 750 gulden per ton, they would have to find 7,200,000 gulden if they were to dispose of the product at 390 gulden per ton. Moreover, the manufacturing risks of 5,000,000 to 6,000,000 gulden would have been borne by the State. If, on the other hand, the Government were willing to give a guarantee of a sale of the product at 750 gulden per ton, and of cheap fuel, then the company was ready to bear the manufacturing risks. A preliminary agreement was first concluded with J. Verheijen, by means of a Bill presented to the Dutch Lower House in 1918. The Dutch Nitrogen Commission, to which, among others, J. H. Aberson, S. Hoogewerff, A. ter Horst, D. Knuttel, J. C. A. Simon Thomas and G. H. Voorhoeve belonged, reported favourably on the actual process, but unfavourably on the economic basis of the project; the Government rejected the project, in spite of the serious lack of nitrogen compounds, in view of the unlikelihood of successful competitive operation by the undertaking after the War; it also refused to consider any similar plan.

Negotiations with a syndicate which proposed to develop the process of L. Hamburger proceeded more favourably. L. Hamburger and Bucher, in America, produce sodium cyanide and ammonia. A company was formed under the name of N.V. Stickstofbindungsindustri Nederland, with a total capital of 10,000,000 gulden, of which 3,000,000 gulden were paid up on formation. The agreement between the Government and this company was ratified by the Second Chamber in 1918. The Government agreed to purchase definite quantities of fixed nitrogen over a period of six years at fixed prices, the minimum being 2,500 tons, and the maximum 5,000 tons. The Government also agreed to the following additional premiums :—

	Per 100 kg.
For delivery of ammonium sulphate before April, 1919	6 fl.
For delivery of ammonium sulphate from May 1st to August 1st, 1919	4 ,,
For delivery of ammonium sulphate between September 1st and December 31st, 1919 . . .	2 ,,

An expert commission reported very favourably on the process. The erection of a works at Dordrecht was commenced at once. It was hoped that experimental working would be started in 1919. The total production is intended to be 12,500 tons of ammonium sulphate in the first instance, in order to satisfy the most urgent requirements of Dutch agriculture. The capital consists of 9,950,000 gulden in ordinary shares and 50,000 gulden in preference shares. On the formation of the company in 1918, the preference shares and 2,950,000 gulden of the ordinary shares were paid up. In the interval, experimental working at Dordrecht had given favourable results, and it is expected that all remaining difficulties will soon be overcome.[1]

L. Hamburger, of Utrecht, read a comprehensive paper on July 13th, 1918, to the Dutch Chemical Society on the nitrogen question from the Dutch standpoint. In 1919 the sub-commission on the nitrogen question of the " Wetenschappelijke Commissie van Advies en Anderzoek in het Belang van Volkswelvaart en-weerbaarheid " persuaded the Dutch Minister of Agriculture to have investigations carried out by Director de Bruyne of the Kantoor vor Afvalproducten voor den Landbouw, Rotterdam, on the collection of fertilisers produced from farmyard manure and peat litter. A proposal of the commission was agreed to that the platinum necessary for the conversion of ammonia into nitric acid should be acquired by the State.

In 1918 six of the largest firms in the beet sugar industry decided to establish a works for the fixation of atmospheric nitrogen. In the first instance, 50,000 gulden were contributed for this purpose. Similar plans were entertained by the Naamlooze Vennootschap Amsterdamsche Superfosfaat-Fabriek and the Vereenigde Chemische Fabrieken. The profits were to be divided amongst the participating firms. The Superphosphate Company simultaneously increased its capital from 3,000,000 to 6,000,000 gulden. Apart from sulphuric acid, and superphosphate, it has also produced hydrochloric and nitric acids since the outbreak of war. The Mij. van. Zwavelzuurbereiding v.h.G.T. Ketjen en Co., of Amsterdam, manufactures sulphuric acid by both the lead chamber and the contact processes.

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 404.

The main producer of ammonia and so forth is the N.V. Ammoniak-fabrick v.h. Van der Elst en Matthes, of Weesp, which produces crude ammoniacal liquor, pure aqueous ammonia, ammonium sulphate, ammonium carbonate and ammonium nitrate. At the exhibit of inorganic chemical preparations at the second Utrecht Fair in 1918 [1] ammoniacal compounds produced in the manufacture of bone charcoal were also shown.

The Arnhem Gas Works manufacture many ammonia compounds. Until 1914 this works merely produced ammoniacal liquor and ammonium sulphate, but at a later date liquid ammonia for the refrigerating industry was also produced, for which purpose the ammoniacal liquor of the works was supplemented from other gas works. Ammonium chloride is also produced.

Among newly formed companies may be mentioned the N.V. Zuurstoff-Fabriek "De Allblas" and the N.V. Acetyleengas Maatschappij; it was also intended that a carbide works should be erected near the Limburg colliery (1918). Before the War, in Holland, 100 kg. of carbide cost 18 gulden, whilst in 1918 it cost 1·3 gulden per kilogram.

It was stated in the English House of Commons in 1917 that the total annual imports of fertilisers into Holland in the years 1911–13 averaged 1,301,000 tons. After deducting the re-exports, there remained, on an average, 556,000 tons per annum for home consumption. The actual imports in 1916 were, however, 157,000 tons in all. The excess of imports of the most important fertilisers in 1912 and 1913 were as follows :—

	1912. Tons.	1913. Tons.
Chile nitrate	74,406	82,490
Ammonium sulphate	7,958	12,475
Guano	2,344	11,345
Basic slag	165,485	240,259

The agreement concluded between the Netherlands and the Entente Powers provided for the following quantities of fertilisers for 1918–19 : 45,000 tons of Chile nitrate and 40,000 tons of crude phosphate. A comparison of these figures with those of the above table will show how poorly Holland was supplied with fertilisers during the War.[2] The imports of Chile nitrate in 1913 amounted to 203,585 tons.

An agreement was concluded in 1919 between the Dutch Government and the Chilean Ministry of Finance, according to which the

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 384–385.
[2] *Chem. Ind.*, 1916, p. 174.

nitrate producer, Don Jorge Sabioncello, sold 22,000 tons of Chile nitrate to Holland at a price of 13*s*. 6*d*. per cwt. The necessary transport was successfully found in Dutch vessels, and consequently considerable quantities of nitrate could be imported in the first quarter of 1919, amounting to 80,000 tons until the end of April. The freight rate was 59 to 75 gulden per ton. On July 18th, 1919, the Dutch Ministry of Commerce granted free trading facilities in Chile nitrate, calcium nitrate, cyanamide and foreign ammonium sulphate. On January 1st, 1920, 27,000 tons of Chile nitrate were available from the Kunstmestcommissie (Commission for Artificial Fertilisers). During the next few months a further 56,188 tons were imported, so that at least 83,188 tons were available for the spring manuring of 1920 alone, compared with a consumption of only 100,000 tons per year before the War. The imports increased still further, and in the summer of 1920 had already exceeded 125,000 tons. The price of Chile nitrate had dropped. On the Rotterdam Exchange it was 60 to 62 gulden per 100 kg. on March 15th, 1920, only 20 gulden on May 18th, 1920, and 18 to 20 gulden on July 6th, 1920.

In 1919, under the leadership of the N.V. Ammoniak Fabriek voorheen Van der Elst & Matthes, a number of Dutch municipal gas works combined to form an association for the sale of ammonium sulphate, which controlled 85 per cent. of the Dutch production. Sales were conducted by the new Verkoopkantoor voor Zwavelzuren Ammoniak in Amsterdam. There are no exports. The market price is about 34 to 35 gulden per 100 kg.

The prices per 100 kg. in Rotterdam on July 1st, 1920, were as follows: ammonia, 18 to 20 gulden; calcium carbide, 20 to 22 gulden; potassium cyanide, 235 to 275 gulden; sodium cyanide, 200 to 225 gulden; sulphuric acid of 60° Bé., 13 to 14 gulden.

Russia.—As this country has, for the present, no large nitrogen industry, it is entirely dependent on imports, on ammonia from coke ovens, and on its natural resources. There are small nitrate deposits in the Altai Mountains, Siberia, at Jalutorowska, Siberia, and near the Urmia Lake in Persia. At the last locality about 32·8 tons of nitrate were obtained in 1915–16, of which half had to be supplied to the Persian Government Arsenal. Before the War 30,000,000,000 roubles were invested in industrial undertakings, which had an output value of about 7,000,000,000 to 8,000,000,000 roubles per year and about 3,000,000,000 roubles were invested in chemical industry; the number of workpeople employed in this industry doubled during the War, and was then about 400,000.

The imports of Chile nitrate into Russia in 1913 were 43.359 tons,

but after the outbreak of war importation became very difficult, as the only available harbour for imports was Vladivostock. In the spring of 1915 the stocks of Chile nitrate were 80 per cent. less than in 1913, and 444 per cent. dearer. At that date superphosphate had increased in price by 93 per cent., potash salts by 27 to 35 per cent., and lime by 40 per cent. The price of ammonium sulphate alone had dropped, as it could not be exported. After the autumn of 1917, phosphate, lime, Chile nitrate, calcium nitrate and potash salts vanished completely from the market. The domestic production of phosphate in 1913 was 11,200,000 pud, and in 1916 3,500,000 pud (1 pud = 16·3805 kg.). The imports in 1913 were 23·2 million pud. The imports of potash salts in 1913 were 5,000,000 pud. In the Moscow district at the commencement of 1917 100 kg. of nitrate already cost about 66 marks, compared with 24 marks in 1914. The chemical works then demanded free imports for their requirements, and established a special buying organisation in Chile. In 1916 the Russian Government seized all shipments to Vladivostock, paying about 300 marks per ton for refined nitrate, and 240 marks per ton for crude nitrate. The only quantities exempt from seizure were those which had been unloaded in London with permission of the Russian Government Commission. Large deposits of phosphorite have been found in the Governments of Perm and Kostroma. In 1916 the production of nitrate in Russia was 300,000 pud.

In spite of the very greatly developed coal production and the fairly important production of coke, there was already a shortage of ammonium salts in 1915. The production in thousands of tons was as follows :—

	Coal Production.	Coke Production.
1855	1,557	—
1895	9,099	—
1900	16,157	2,244
1905	18,688	2,301
1910	23,927	2,750
1913	30,745	3,816

There are in Russia 380,000 sq. km. of peat moors, but the peat industry is still in a most primitive condition. Parts of Southern Russia are very rich in natural gas resources. The gas contains 93·66 per cent. of CH_4 ; 0·2 per cent. of CO ; 1·08 per cent. of H_2 ; 1·10 per cent. of O_2 ; 3·35 per cent. of CO_2 ; 0·61 per cent. residue ; the calorific value is 8,969 cals. per cu. m. Hitherto the gas has been scarcely used for purposes of chemical industry, nor have the water-powers in the mountainous districts been utilised. Quite recently the organisation of power resources has become important.

In 1919 the Omsk Government authorised the exploitation of the combustible mud of Lake Schiwakisch. This mud is stated to yield tar, cyanide, ammonia and other products on gasification. A number of works were to have been erected in 1919. The A.G. Perun, among others, possesses carbide furnaces.

In 1917 a company was formed in Petrograd in order to erect an atmospheric nitric acid works in conjunction with the Norsk Hydro, utilising the Birkeland-Eyde process. Subsequent political developments prevented the execution of this project, but during 1919 and 1920 the plans were reconsidered. The Supreme Industrial Commission decided to erect several works for the production of nitric acid. The first of these works was said to have progressed so far at the commencement of 1920 that it could start manufacture. This works is expected to produce at least 16,000 to 22,000 kg. of nitrate annually. In other respects the Soviet Government has favoured the development of chemical industry; thus the Supreme Industrial Commission proposes to devote special attention to the erection of phosphorus works for the manufacture of matches. In 1913 43,359 tons of Chile nitrate were imported.

The Russian Government Department for Mineral Fertilisers was able to supply the following quantities in 1917:-

1,000 tons of superphosphate from Ochta,
1,000 tons of superphosphate from Samara,
2,500 tons of superphosphate from Vladivostock,
900 tons of ammonium sulphate, and
200 tons of Chile nitrate.

In the same year lectures were given on the use of artificial fertilisers.

In 1919 the Agricultural Section of the Central Advisory Board of Experts carefully investigated the question of the supply of Russia with nitrogenous fertilisers. It came to the conclusion[1] that Russian agriculture could not reckon on a supply of nitrogenous fertilisers in the near future, as Russia had no atmospheric nitrogen industry (the establishment of which was strongly recommended), and as, moreover, the German prohibition of exports was still in force, and finally the extremely difficult transport conditions prevented the importation of Chile nitrate through Vladivostock. It is said that there are still old stocks at that port. Norwegian imports could not be relied on, on account of the high price and the relatively small quantities which could be obtained from that source. The Committee advised the careful exploitation of available nitrogenous products, such as stable manure, peat and industrial by-products, the encouragement of the cultivation of nitrogen-fixing leguminous

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 402.

crops, and the rapid development of industrial methods of the production of nitrogen compounds. Among these most weight is laid on coke ovens, gas works, gasification of peat and so forth. Among methods of fixation of atmospheric nitrogen, the most valuable was considered to be a process of Professor Meiner, which is said to be in operation at the Skoda Works in Pilsen. A commission was established in 1918 to study this process on the spot.

The Reports of the U.S.A. Bureau for Internal and External Trade are of very great interest, being written from the standpoint of a future economic penetration of Russia, which was first planned by Vanderlip in 1920:—

"Russia possesses enormous beds of phosphorite, but the mineral is not of high quality. Before the War 300,000,000 pud of iron were produced, and a somewhat smaller quantity of coke. If the output were increased by 1,000,000,000 pud, 6,000,000 pud of ammonium sulphate could be obtained as a by-product. In European Russia alone there are 17,000,000 desjatines of peat moors (1 desjatine = approximately 1·09 hectares). By gasifying peat, cheap power-gas and ammonium sulphate could be obtained. It is calculated that 5,000 desjatines of peat moors, 2 to 3 m. thick, would yield 24,000,000 pud of ammonium sulphate and about 1,500,000 h.p. at $\frac{1}{4}$ to $\frac{1}{2}$ kopeck.

"One ton of dry peat is said to yield 2 to $2\frac{1}{2}$ pud of ammonium sulphate. A combination of the Caro process with the Gering-Viland process, in which tar and ammonia are obtained as by-products in the manufacture of coke from peat for metallurgical purposes, would supply Russia with cheap power in such quantities that its employment might be considered for the manufacture of nitric acid from air, of calcium carbide, aluminium and wood-pulp, and for the development of a wood-product and metallurgical industry.

"A works has been erected for the production of nitric acid from the air, on the Kiwatsch Falls of the Suna River, at which 25,000 h.p. are available, the output capacity being 400,000 pud of nitrate. In order to produce 24,000,000 pud of nitrate, it would be necessary to have power stations of 400,000 h.p., which could easily be supplied with the necessary water power from the falls in the Altai, in the Caucasus and in the Murman territory. At a later date further industries will probably be developed, the products of which were imported into Russia on a large scale before the War:—

"(1) Calcined soda; of which 200,000 pud were imported from Germany and England before the War.

"(2) Artificial carbon and graphite.

"(3) Aluminium (of which about 300,000 pud were imported before the War).

"(4) Magnesium, sodium and phosphorus.

"For the production of these products on a sufficient scale—namely, 500,000 pud of calcined alkali, 1,000,000 pud of artificial carbon and graphite, 10,000 pud of magnesium, 5,000 pud of sodium, and 7,000 pud of phosphorus—power stations of a total output of 470,000 kw. would be required, of which 300,000 kw. could be obtained from 1,500 to 2,000 desjatines of peat and 170,000 kw. by the development of water powers.

"It is evident that all-in-all gigantic economic developments are possible."

Finland.—More than 12 per cent. of the surface of this country is occupied by lakes, the large number of which have caused it to be called the "Land of the Thousand Lakes." Under these circumstances the mountainous portions of the country are naturally rich in water powers. The important Imatra Falls are situated at the point where the Saima River penetrates the Salpausselkä Ridge; these falls are connected with Lake Ladoga by the Vuoksen River. The total area of the country comprises 372,612 sq. km., of which 47,829·3 sq. km. are lakes, and 65,000 sq. km. are moors.

In 1918 the first application was made for a concession for the establishment of a large power station at the Imatra Falls. The earlier projects estimated the cost of this power station at 25,000,000 to 30,000,000 Finnish marks, but in 1918 it was estimated at 100,000,000 marks. The height of the falls is 21 m. at some points. It was originally intended that the power station should supply the town of Petrograd, but the present project is that 118,000 h.p. at the turbine should be utilised for the establishment of a national nitrogen fixation works. In 1918 the cost per horse-power year was estimated at 100 Finnish marks, and the total return, therefore, at about 10,000,000 Finnish marks. It is said that 500,000 h.p. are obtainable from the Vuoksen Falls. The water power of the Kymmeneälf is already partially exploited.

J. Palmen read a comprehensive paper on the nitrogen problem before the Finska Keminstsamfundet, Helsingborg, on October 9th, 1918, based on the report of Charles L. Parsons to the American Government.[1] In the subsequent discussion Aschan stated that during his visit to Germany he had heard that the Haber-Bosch process was the most promising, and that at that time the

[1] *Chem. Ztg.*, 1919, p. 403.

American cyanide process was quite unknown. It was decided to recommend the latter to a private undertaking in Finland, and in any case to experiment on it in the central Finnish laboratories. German capital was to be utilised for the erection of a works using the Haber-Bosch process, and this works was later to be placed under Government control. It was decided to despatch a commission for the study of nitrogen problems to Sweden, Norway and Germany, and to form a committee which should concern itself with the question of the supply of nitric acid for the Finnish explosive industry. Finnish professional circles then established contact with the German nitrogen industry.

The manufacture of carbide is carried out by the Elektrometallurgiska Aktiebolaget at Vuoksenniska and Nokia. The product is utilised by the very rapidly growing acetylene lighting industry. The whole carbide trade is in the hands of the Järnkontoret A.B. in Helsingfors.

Timber was formerly the most important Finnish export, and the Finnish timber industry, which formerly earned about 100,000,000 Finnish marks annually, suffered seriously through the War. Increased attention has been devoted to the utilisation of the peat moors. The manufacture of powdered peat has once more been taken up. Good results were obtained in the utilisation of peat as a fuel for locomotives in 1914–15, and the product of the powdered peat works at Richimjäki had been permanently introduced for the purpose. The Finnish newspaper, *Jeknillinen Aikakanslehti,* of Helsingfors, published a special number in 1920 on the peat fuel industry.

An announcement was made on October 4th, 1919, that Chile and Norway nitrate, ammonium sulphate, potash fertilisers, cyanamide and other products could be imported duty free.

The moors of **Latvia** and **Lithuania** are quite important, and comprise 3,840 sq. km. of a total area of 47,000 sq. km., but their total area is very much smaller than that of the Finnish moors. In **Esthonia**[1] the English Carboyl Syndicate proposes to develop the oil shale at Wannamois on the Padda River.

In **Bulgaria** carbide and artificial fertilisers are manufactured a Peruschtitza.

On the basis of the estimates given in the preceding chapters, we have compiled the following table on the output capacity of the plants in the various European countries in 1919–20 (the figures are, of course, only approximate):—

[1] *Chem. Ind.*, 1921, p. 76

	(1) Cyanamide process, in tons of calcium cyanamide.	(2) Nitric acid by the arc process, catalytic process, etc., in so far as not comprised in other columns; expressed in tons of calcium nitrate.	(3) Cyanide ammonia processes and ammonia from cyanamide, not included in the first column, in tons of ammonium sulphate	(4) By-product ammonia from coke-ovens, gasworks, etc., in tons of ammonium sulphate.	(5) Cyanide from atmospheric nitrogen in tons of KCN.	(6) Haber-Bosch process, etc., in tons of ammonium sulphate.	(7) TOTAL, in tons of nitrogen.
(a) Germany	500,000	Small.	—	300,000	5,000	750,000	311,100
(b) Norway	250,000	156,000	10,000	—	—	—	78,625
(c) Sweden	75,000	—	5,000	—	—	—	16,000
(d) Switzerland	30,000	10,000	—	—	—	—	7,700
(e) France	300,000	75,000	—	75,000	—	—	88,000
(f) Great Britain	—	10,000	—	380,000	3,000	—	78,358
(g) Belgium	—	—	—	40,000	—	—	8,000
(h) Italy	70,000	25,000	—	—	—	—	18,325
(i) Holland	—	—	12,500	—	—	—	2,500
(k) Austrian Succession-States	75,000	15,000	—	—	—	—	17,600
(l) Remaining countries of Europe	—	—	—	175,000	—	—	35,000
Total	1,300,000	291,000	27,500	970,000	8,000	750,000	—
Nitrogen content in tons of Nitrogen	260,000	50,000	5,500	194,000	1,700	150,000	—
TOTAL, IN TONS OF FIXED NITROGEN							661,200

For causes which we have repeatedly discussed, only one-half to one-third of this quantity was actually produced in 1919. We must, however, add about 12,000 tons of cyanide, ferro-cyanide, etc., from spent oxide, etc., equal to 1,700 tons of nitrogen, so that a total nitrogen output of 662,900 tons annually is obtained.

Supplement, 1921–24

Belgium.—For the present, by-product coking is alone of importance. The average monthly production for 1913 was 1,903,460 tons of coal, 293,580 tons of coke, and the average monthly production in 1922 was 1,769,514 tons of coal and 225,624 tons of coke. The output of ammonium sulphate from the coke ovens was 22,696 tons in 1914 and 9,048 tons in 1920. The production capacity in 1920 was only 25,000 tons. The imports were 10,569 tons of Chile saltpetre, 19,977 tons of calcium nitrate and 33,493 tons of ammonium sulphate (*Chem. Ztg.*, **1922**, 500; *Chem. Ind.*, **1923**, 481). The

Ougré-Marihaye Blast Furnaces, founded in 1923, in association with the French Claude Co., the Société Belge de L'Azote in order to erect a Claude ammonia plant.

Italy.—The main feature of the nitrogen industry is the production of calcium cyanamide, which achieved a maximum annual production of 75,000 tons and is carried out in the works at Piano d'Orta, Collestatte, Papignano, Narno, St. Marcel and Ascoli Piceno. A further plant is being erected at Domo d'Ossola.

13,000 tons of ammonium sulphate are produced, and a production of a further 5,000 tons is in view, of which 2,500 tons will be produced by the Casale and Fauser processes.

In 1922 there were also produced 40,000 tons of calcium cyanamide 50,000 tons ammonium sulphate, and 1,000 tons ammonium nitrate.

The development of the synthetic production of ammonia by the processes of Giacomo Fauser and of Luigi Casale are very important, the former being undertaken by the Societá Elettrochimica Novarese. This company makes use of 97 to 98 per cent. nitrogen, as obtained from nitric acid absorption towers and electrolytic hydrogen. One ton of ammonia is produced per day. An increase in the plant to employ a further 8,000 k.w. is planned. 4 new plants are being erected at Sedico Bribano, at Belluno, near Meran, utilising power from the Etsch, and at Firso, in Sardinia. Plants using the Casale process were erected at Rumianca and at Terni in 1920 by Soc. Italiana Ammon-Sintectica. Licences have been granted through the Ammonia Casale Company at Avignon, France; Sabinanigo, Spain; Nobloka, Japan; Niagara Falls, U.S.A.; Visp, Switzerland (*Chem. Ztg.*, **1923**, 864; *Metallbörse*, **1923**, 2073). The Azogeno-Societá-Anonime per la Fabbrication dell'Ammoniaca Sintectica et Prodotti Derivati operates the Claude process.

The works utilising the arc process at Legnano and Ponte Mammolo have closed.

The 17 carbide works suffered in 1923 through over-production. In 1915 there were only 4 such works.

Spain.—*Chem. Ztg.*, **1922**, 548; **1923**, 382, 465; *Metallbörse*, **1923**, 2073. A Claude plant is being erected at Flix, which is to produce 1 ton of ammonia per day. A Casale plant has been completed at Sabinanigo.

Portugal produced 13,000 tons of ammonium sulphate in 1913 and only 30 tons in 1919.

Denmark.—A commission was formed in this country in order to investigate the conditions for the establishment of an internal nitrogen industry, but the economic conditions are unfavourable (*Chem. Ztg.*, **1921**, 196; **1922**, 1120).

Holland has recently successfully established the synthetic production of cyanamide. N.V. Stickstofbindingsindustrie Nederland, was founded in 1918, and operates according to a process devised by L. Hamburger (*Chem. Ztg.*, **1922**, 124, 700 ; *Chem. Ind.*, **1923**, 69).

Russia.—The production of coke in the Donetz Territory has developed rapidly since 1915. In the Donetz region the production of benzole was 12,500 pud in 1913, and 1·04 million pud in 1917 ; in 1919 a production of 2,000,000 pud might have been expected. There are 17 coke-oven batteries, comprising 1,912 ovens, which work without by-product production, and 22 batteries, comprising 2,000 ovens, with by-product production. 2 works were incomplete, 3 have Valentiner nitric-acid plants, and 1 is arranged for oxidation of ammonia by the Ostwald process, but the platinum has been stolen. The effects of the Revolution were extraordinarily severe. Whereas 34,750,000 tons of coal were produced in 1913, only 9·643 million tons were produced in 1922. To-day the industry is organised into numerous trusts, in which the State is interested, which, for example, receive payment in wheat for the nitrogenous manure which they supply to the Agricultural Economic Groups. The Trust controlling coke and benzole was only operating 5 plants during January and February of 1923. The Ural Nitric Acid Works are stated to have produced 23,000 puds in 1923 (*Chem. Ztg.*, **1921**, 297/8 ; **1922**, 415, 691, 1010/1 ; *Metallbörse*, **1923**, 22, 264, 360, 1079, 1914).

Finland.—In this country the Electrometall A.G. Vuokseniska produced small quantities of carbide (*Chem. Ztg.*, **1921**, 1064 ; **1922**, 111, 635, 720).

Roumania.—With the help of power derived from natural gas containing 99 per cent. methane, cyanamide and nitric acid are produced at Dicio-San-Martin (*Chem. Zentralb.*, **1922**, ii., 26).

Europe.—On comparing the statistics of the National Institute of Agriculture at Rome (*Chem. Ztg.*, **1922**, 691), with the figures of the author, a production for 1920–21 is arrived at of 350,000 tons of fixed nitrogen per annum, the greater part of which consists of ammonium sulphate ; the substance second in importance is calcium cyanamide.

CHAPTER XI

The Development of the Nitrogen Industry in the United States of North America[1]

In respect to water-power resources, the United States surpass all other countries. The great falls of Niagara have served the electro-chemical industry for a considerable time. The first power station at Niagara was built in 1894. The eastern part of Niagara Falls, the American or Fort Schlosser Fall, is 326 m. wide and 47 m. high in the centre, whilst the western, Great or Horse-Shoe Falls, are 574 m. wide and 44 m. high. It is estimated that the total amount of water passing both falls in one second is about 6,000 cu. m. It is assumed that were Niagara totally utilised, 7,000,000 h.p. could be obtained. At present 265,000 h.p. are developed on the American side and 388,500 h.p. on the Canadian side. In order to preserve the natural beauty of the falls an agreement was concluded in May, 1910, between the United States, on the one hand, and Canada and Great Britain on the other, that the United States might employ 20,000 cu. ft. (560 cu. m.) per second, and the Canadian works 36,000 cub. ft. (1,019 cu. m.) of water per second for power production—that is, a total of 26·4 per cent. of the flow. As the former Burton Law only allowed 15,600 cu. ft. (441·5 cu. m.) to be removed per second from the American side, the industry approached the Government during the War with a view to obtaining a concession for the remaining 4,400 cu. ft. (80,000 h.p.) which had hitherto been refused.

At the Falls the vertical shafts, which are driven by turbines at the bottom, are connected above with cylindrical current generators. The cheap electric energy from Niagara Falls enabled C. G. Acheson technically to develop his graphite process and Willson to erect his first carbide furnace, which required only 200 h.p. All the products of large-scale electro-chemical industry are now being produced at Niagara Falls.

The total available energy on the St. Lawrence River at low water is 1·8 million h.p.

In the United States there were 5,221 electric power stations in 1912 and 6,541 in 1917. Their total revenue in 1917 was $527,000,000

[1] See especially *Journ. of Ind. and Eng. Chem.*, 1919, ii., 231; *Chem. Ind.*, 1919, 243.

and their expenses $427,000,000. The power output in 1917 was 12·8 million h.p., of which 8·4 million h.p. were obtained by steam and 4·4 million h.p. from water power. The average horse-power of steam engines increased from 334 h.p. in 1907 to 631 h.p. in 1912 and 1,124 in 1917 ; 85 per cent. of the total electric power is developed in public power stations. In utilising electric power plants, if the annual power factor is increased to 90 or more per cent., the power-costs are correspondingly decreased. In Germany there are very few plants with an annual power factor of 70 to 80 per cent. ; in North America, however, the power factors are as follows :—

	Annual Output in K w.h.	Power Factor. Per cent.
Niagara Falls Power Company .	2,000,000,000	92·2
Ontario Power Company .	1,600,000,000	81·9
Toronto Power Company. .	900,000,000	81·9

In 1918 an overland transmission line of aluminium, 90 km. long, was removed by the Montana Power Company and replaced by copper mains. The aluminium cable had been used for fifteen years. Too many repairs had, however, been necessary, due to the properties of aluminium. Aluminium is softer and weaker than copper, and the metal is therefore easily damaged, especially at the point of junction. Aluminium has a low melting-point, burns readily, and is therefore very much more liable to injury by short circuits or by lightning. When attaching aluminium cables to suspension insulators, the effect of wind must be considered, as it often causes dangerous oscillation of the light cable. Danger of fire and to human life is considerably greater in the case of aluminium cables than with copper cables.

American water powers are being very rapidly developed. It is even feared that the supply of power will be excessive when normal conditions have been restored, and the employment of this power, more particularly for increased production of nitrogen compounds, has been considered.

E. J. Pranke, of the American Cyanamide Company, has published several comprehensive papers on the development of individual branches of the American nitrogen industry.[1] Processes of manufacturing nitric acid from Chile nitrate have been so perfected that an average nitrogen yield of 92 to 94 per cent. can be

[1] *J. Ind. Eng. Chem.*, 1918, p. 830; *Chem. Trade Journ.*, 1918, p. 341 ; *Chem. Met. Eng.*, 1918, p. 395 ; *Chem. Zentralbl.*, 1919, ii., 243, 659 ; iv., 72.

relied on, as against 78 to 80 per cent. formerly. The method of heating the retort has been considerably improved. In place of retorts and condensing plants of stoneware, ferrosilicon alloys, such as duriron and tantiron, are now employed. In 1913 there were manufactured in the United States about 89,000 tons of acid, calculated as 100 per cent. HNO_3. The raw material was exclusively nitrate, as the experimental plants for production of nitric acid from the air then played no serious part. During the War the production of nitric acid by the oxidation of ammonia alone amounted to 225,000 tons of 100 per cent. acid per year, in addition to which a further 650,000 tons of 100 per cent. acid were obtained from Chile nitrate. E. J. Pranke [1] estimates the world's production of cyanamide at 270,000 tons, of which 64,000 tons were manufactured at Niagara Falls. In 1916 the military authorities estimated the minimum amount of nitric acid which the United States would require for their own consumption in case of war at 180,000 tons of concentrated acid. In order to produce this by the arc processes, 540,000 h.p. would be required, whereas in order to produce the same amount by the cyanamide process (with conversion into ammonia, which is then oxidised to nitric acid), only 100,000 h.p. would be required. Before the War, in the United States, 85,000 tons of nitrate annually were used in the fertiliser industry, and about 20,000 tons for nitric acid manufacture. On the other hand, the nitrogen demand for 1920 was estimated at about 210,500 tons of nitrogen. Of this, 84,000 tons could be supplied by by-product coke ovens, and 37,650 tons by the nitrogen plant at Muscle Shoals. The remaining 88,850 tons of nitrogen must be imported. Since 1914 the American Chemical Society repeatedly investigated nitrogen problems in detail at their meetings. It was realised in America that the fertiliser industry is the backbone of the question of nitrogen fixation, as the large demand for military purposes cannot be normal. Coke-oven ammonia is considered as a standard in considering the economic status of the synthetic processes. In order to be technically successful, a nitrogen fixation process must be able to supply potassium nitrate, ammonium nitrate, or ammonium phosphate at a reasonable price.

Before the War American agriculturalists used far too little fertiliser, as was clear from the steadily increasing figures for the imports of food supplies and their rise in price. The prices of foodstuffs increased by 80 per cent. between 1896 and 1912. In Germany the average crops from any given area have increased by 50 per cent.

[1] *J. Ind. Eng. Chem.*, 1914, p. 415.

during the last twenty years, whereas in the United States, they have increased by only 20 per cent.

American expert circles always expressed themselves in favour of the production of ammonia, including the preliminary stages of the production of cyanamide and cyanide. Under American conditions arc processes must be restricted to the manufacture of nitric acid, as the production of nitrate could not pay. On the other hand, any quantity of nitric acid can be obtained from ammonia, by the catalytic oxidation process. In America the main part in synthetic processes is played by the cyanamide process, if only for the one reason that its primary product can be utilised directly without further transformation, whilst it readily yields ammonia, urea and cyanide.

Naturally, the utilisation of cyanamide as a fertiliser has been assiduously studied. Fertiliser experiments (for example, at the experimental station at Rothamsted, England) have always proved favourable. The objections which have been made to the use of cyanamide are mainly the following :—

(a) Carbide contents,
(b) Nitrogen loss on storage,
(c) Dusting.

The carbide contents are reduced to a very small amount, both in American and German works, by treatment with water. The alteration in weight on dry storage, according to American determinations, is, on the average, only 1 per cent. per annum, and the reduction in nitrogen contents under the same conditions only 0·036 per cent. The caustic action on the skin through dusting can be avoided by smearing with fat, by the use of tightly closed distributors, and by avoidance of indulgence in alcohol. American sources do not report on oiled cyanamide, which is recommended by the German works,[1] but, on the other hand, they emphasise the fact that they could not introduce granulated, dust-free, cyanamide, in consequence of its higher price.[2] Special attention is also directed to the fact that the results of small pot cultures do not always coincide with those actually obtained in practice in open farming. This is particularly true of mixed cyanamide fertilisers, which are usually used too freely and then exert a corrosive action, or often behave as organic nitrogen compounds, and cannot be considered as equivalent to the usual inorganic fertilisers. It has also been found in practice that mixed fertilisers containing various nitro-

[1] Siebner, *Umschau*, 1920, pp. 488 *et seq.*
[2] E. J. Pranke, *J. Ind. Eng. Chem.*, 1914, p. 415.

genous compounds are superior to unmixed fertilisers in productivity. The best mixture for American soil is 90 kg. of cyanamide per acre, or a corresponding quantity of mixed fertiliser, with occasional addition of other nitrogen compounds. For acid, light, sandy soils, 112 kg. of cyanamide per acre is recommended, admixed with lime.

It is an accepted rule in Germany that cyanamide and superphosphate should not be mixed, and that even admixture with basic slag should only be carried out immediately before distribution.[1] In America, on the other hand, cyanamide is almost exclusively used admixed with acid phosphate, and, in the case of sandy soil, admixed with a little basic slag. The following reactions then take place in the soil :—

$$CaCN_2 + 2H_2O = CaO + CO(NH_2)_2,$$
$$CaH_4(PO_4)_2 + CaO = 2CaHPO_4 + H_2O.$$

Thus, dicalcium phosphate and urea are formed ; the latter is then either immediately assimilated or reacts with the constituents of the soil to form only slightly soluble ammonium double salts, which are not readily washed away, and are therefore very effective. The constituents are mixed in the right proportions ; in the commercial mixtures there is only 36 to 68 kg. of cyanamide to 453 kg. of dry superphosphate—that is, relatively small amounts of nitrogen ; thus formation of phosphates insoluble in citrates is not to be feared. A monocalcium tetra-hydrogen phosphate is formed, the phosphoric acid in which is completely available. When mixed with basic slag, the iron and manganese contents of the latter (15 to 18 per cent. FeO and Fe_2O_3, 5 per cent. MnO) are said to catalytically promote the formation of urea. The following are claimed as special advantages of mixed cyanamide fertilisers : low price, drying action on hygroscopic constituents of the fertiliser, fixation of acid, lime contents, and availability in place of expensive organic fertilisers, such as blood meal, bone meal, and so forth.

In an address to the President, the Minister of War and the Secretary of the Navy, the American Electro-chemical Society [2] deals in detail with the question of nitrogen supply. In this communication the following recommendations are made :—

(1) Immediate importation and suitable storage of such quantities of Chile nitrate that war requirements are met for eighteen months ;

(2) An investigatory commission, in order to compare all processes relating to the nitrogen industry ;

[1] See W. Moller and L. Sendler, "Düngemittel, künstliche" in Ullmann's "Encyclopædia."

[2] *Chem. Ztg.*, 1916, p. 847.

(3) The working of suitable processes should be left to private enterprise, the immediate erection of a Government plant should not be considered, but, on the other hand, the exploitation of natural water powers on a larger scale than hitherto should be rendered possible; and

(4) Investigations should be directed to the study of the production of ammonia and the activity of nitrogen-assimilating bacteria.

We will describe below how all these negotiations and addresses led to the development of a large domestic nitrogen industry in the United States, calculated not only to supply the necessary fertilisers,[1] but also to provide for national defence. At the close of 1919 Senator Wadsworth introduced a resolution in Congress advocating the formation of a self-contained central organisation for the production of atmospheric nitrogen compounds and so forth for military, experimental, fertilising, and other purposes.[2] Research laboratories and experimental plant were to be provided for this purpose.

The few figures which we have already quoted indicate the enormous development of chemical industry in the United States since 1914. The interest of Americans in chemical industry has been greatly stimulated, and this result may have been largely due to the exhibitions of chemical products which were from time to time arranged in all parts of the country. The National Exhibition of Chemical Industry in New York, from September 20th to 25th, 1915, already attracted eighty exhibitors, although at that time the large chemical works very largely refused to take part. Many cinematograph performances have been arranged to explain chemical manufactures and to emphasise their importance and economic value. The most active agency in this direction was the Jordan Scientific Society of Bates College, Lewiston, which owns cinematograph films representing the working of by-product coke ovens, the manufacture of cyanamide and Cottrell's dust precipitation process.[3]

The increase of capital in the chemical industry of the United States is shown by the following table[4]:—

	New Capital Invested.
August, 1914, to August, 1915	$ 16,800,000
,, 1915 .. 1916	,, 65,565,000
,, 1916 ,, 1917	,, 99,244,000
,, 1917 ,, 1918	,, 146,160,000
,, 1918 ,, 1919	,, 73,403,000
,, 1919 ,, 1920	,, 112,173,000

[1] "Ernahrung d. Pflanze," 1916, p. 149.
[2] *Zeitsch. f. angew. Chem.*, 1920, ii., 13.
[3] *Chem. Ztg.*, 1919, p. 701.
[4] *Zeitsch. f. angew. Chem.*, 1920, ii., 59; *Chem. Ztg.*, 1920, p. 296.

The total is more than 513·3 million dollars. During this period the American Government is stated to have invested $300,000,000 in chemical works, of which $116,000,000 were invested in the nitrogen industry alone.[1]

An indication of the depreciation of assets, created during the War, at the conclusion of peace, is given by the fact that one firm sold for $6,000,000 plant which was erected at a cost of $100,000,000. The exports of explosives amounted to $6,000,000 in 1914 and about $803,000,000 in 1917. At the close of 1918 and the commencement of 1919 a whole number of explosive and works were closed. At the outbreak of war there were only 6 colour works in the United States, only one of which produced aniline dyestuffs. In the course of the last few years about 100 new chemical works have come into being, of which 22 manufacture coal-tar dyestuffs, the imports of which amounted, before 1914, to $10,000,000 to $15,000,000 per year. In 1919–20 the dyestuff manufacturers produced about 13,000 tons. In 1914 the total exports of dyestuffs were valued at $350,000, in 1917 at $12,000,000, and in 1918 at $17,000,000. The exports of sulphuric acid rose from 5,400 tons in 1914–15 to 31,000 tons in 1917–18. Caustic soda and similar products, which were hardly exported at all before 1914, were exported in 1917–18 to the extent of 56,700 tons.

In 1914 6,000,000 tons of chemicals were manufactured in the United States, of the value of $2,500,000, and in 1917 these had increased to 46,000,000 tons, of the value of $57,000,000. The production of sulphuric acid, which was already 2,710,000 tons before the War, had increased in 1917 to more than 3,300,000 tons, and the total output capacity of the sulphuric acid works had almost doubled from 1914 to 1920, being 4,970,000 tons in 1919. In 1917 152,760 cu. m. of benzene were produced and 38,760 cu. m. of toluene. Synthetic phenol was not produced at all before 1914, but in 1917 29,000 tons, valued at $23,700,000, were produced in fifteen works. The quantities of pure German potash salts used agriculturally in the United States amounted to 244,911 tons in 1910 ; 231,690 tons in 1913 ; 152,499 tons in 1914, and 5,046 tons in 1915, and in addition, 11,411 tons of K_2O were used industrially in 1913. The domestic potash industry, which was introduced with great vigour, produced 900 tons calculated as K_2O, in 1915, 8,800 tons in 1916, 30,400 tons in 1917, and 50,000 to 60,000 tons in 1918, using as raw materials, salts, brines, alunite, felspar, the dust from cement kilns and blast furnaces, wool suint, molasses, and the ash of seaweed. Prices have recently once more stimulated the American potash industry.

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 419.

Before the War German potash cost in American markets \$40 per ton; in August, 1919, \$90; in the middle of 1920, \$122 in sacks, and \$117 f.o.b. German ports, in bulk, with 12 per cent. discount for July, and 7 per cent. for August and September deliveries. The American consumer also has to pay freight charges of \$5.50 to \$6.50 per ton. The price of German potash in America, in American currency increased about three-fold in 1914, or more than thirty-fold in German currency. Potash fertiliser from Nebraska, on the other hand, was sold up to December in the United States at \$12.50 per ton.[1] If, therefore, the production of the American potash industry were to grow rapidly, the prospects for German potash would to-day be very poor. The domestic American potash industry suffers, however, through working expenses, which have risen more than ten-fold, and even under the most favourable circumstances it will require many years and millions of dollars before the industry can seriously compete, even leaving the technical difficulties entirely out of account.[2]

The conditions in the German chemical industry have been specially studied by Irving A. Keene of the chemical works of the Keene Company, London, and by J. Bebie of the Monsanto Chemical Works, St. Louis, on behalf of the American Chamber of Commerce in London, and they came to conclusions which are very disconcerting as to German prospects in the near future.[3] The Chicago Exhibition of September, 1919, at which the chemical industry was strongly represented, showed that the United States are about to play an important part as competitors on the world's markets,[4] more particularly as they are endeavouring to develop their industry with all their power. The cultivation of industrial and trade relations between Germany and the United States is served by the Techno-Service Corporation,[5] founded in New York in 1920, which is concerned with the exploitation and purchase of patents, the representation of foreign firms, the facilitation of negotiations, and so forth.

In estimating the possible markets of the American fertiliser industry, the following communications are of great interest, made by the President of the National Fertiliser Association at the annual meeting of 1920 at Sulphur Springs.[6] There are 3,442,500 sq. km. suitable for agriculture, of which 2,025,000 sq. km. are at present under the plough, whilst the rest awaits later cultivation or

[1] *Metallbörse*, 1920, p. 1280.
[2] *Zeitsch. f. angew. Chem.*, 1918, iii., 520.
[3] *Chem. Ztg.*, 1919, p. 663; *Zeitsch. f. angew. Chem.*, 1919, ii., 648.
[4] *Chem. Ztg.*, 1919, p. 832.
[5] *Zeitsch. f. angew. Chem.*, 1920, ii., 299.
[6] *Metallbörse*, 1920, p. 1280.

improvement. The Western States at present utilise very little fertiliser, but the case is otherwise with the Eastern States, which cultivate tobacco, the Southern States, which supply cotton and the North-eastern States which produce large quantities of potatoes, all these using fertilisers in very considerable amounts. Cotton, tobacco and sugar beet are typical "potash gluttons." On the average 200 lb. of artificial fertiliser are used per acre; as the present production and import of nitrogenous fertilisers is about 6,400,000 tons, this suffices for fertilising about 288,000 sq. km., whilst the remainder—namely, 1,737,000 sq. km.—remains unfertilised, and should consume 38,600,000 tons of nitrogenous fertilisers. H. Lipman, of the New Jersey Agricultural Experimental Station, estimates the cultivated area which is most in need of nitrogen at 498,150 sq. km. According to his estimate, this is distributed as follows: —

Southern States	149,850	sq. km.	under	cotton.
	81,000	,,	,,	maize.
Middle West	24,300	,,	,,	wheat.
	40,500	,,	,,	oats.
	81,000	,,	,,	maize.
	40,500	,,	,,	grass.
North Atlantic States	4,050	,,	,,	grass.
	8,100	,,	,,	wheat.
	12,150	,,	,,	oats.
	4,050	,,	,,	potatoes.

If 200 lb. of nitrogenous fertilisers are required per acre, then we have a minimum requirement of 11,070,000 tons, of which at present, as already mentioned, only 6,400,000 tons are actually employed. On comparing the three figures—6,400,000 tons for the present supply, 11,070,000 tons for the most important requirements which should immediately be covered, and 38,600,000 tons for later intensified production in the whole agricultural area—the enormous opportunities for extension of the nitrogen industry in the United States are apparent, possibilities which are not surprising if we bear in mind the total area, which, including Alaska, is 9,212,000 sq. km. The magnitude of the future requirements is enhanced if we take into account the reclamation of at least 1,417,500 sq. km. of virgin soil and barren land, which must ultimately occur, and which will utilise a further 31,500,000 tons of nitrogenous fertilisers.

When discussing the Chilean nitrate industry we mentioned the enormous shipments to the United States; these amounted to 2,018,000 tons in 1918 and fell to 440,000 tons in 1919. In spite of the fact that the imports in 1918 were very considerably greater

than the pre-war imports, which were 552,440 tons in 1914, the demand for Chile nitrate in the middle of 1918 for the production of munitions was greater than the total imports and stocks. The War Industries Board and the War Department therefore made it clear to the Department of Agriculture that no supplies of Chile nitrate would be available for agriculture, and that the farmers would have to manage without them. On the other hand, the output of the explosive industry increased enormously, as will be clear from the following statistics of export values in 1914 and 1916 :--

	1914.		1916.
	$		$
Cartridges . . .	6,567,122	..	55,103,904
Dynamite . . .	1,213,600	..	4,173,175
Gunpowder . .	289,893	..	263,423,149
Other munitions . .	1,966,972	..	392,875,078
Total . .	$10,037,587	..	$715,575,306

At the conclusion of the truce the nitrate stocks of the American Government were quite considerable. At the commencement of 1919 they amounted to 226,000 tons in America and 120,000 tons in Chile. In addition, the explosives works themselves held very considerable reserves. At the commencement of 1919 151,000 tons of the Government stocks were distributed to the farmers by the Ministry of Agriculture at a price of about $90 per ton. On June 30th, 1919, the Government control of the nitrate trade was removed. The principal American firm working in Chile is the Du Pont Nitrate Company which, as is indicated by the name, is a branch of the large explosive works, the Du Pont de Nemours Powder Company. During the War this latter company made enormous profits, which it is now utilising for developing the manufacture of dyestuffs on a very large scale.[1]

During the war period repeated attempts were made to exploit the domestic nitrate deposits. In 1917 the Geological Bureau of the United States stated that after a careful investigation lasting for two years and covering all parts of the country, the nitrate deposits had been found to be practically valueless for any technical exploitation, and that they had at most a local importance. In the State of Colorado the nitrate deposits cover an area of 360,000 hectares. In Presido County the Texas Nitrate and Fertiliser Company, Alpine (Texas), is developing deposits. The American Nitrate Company of Boise (Idaho) works in the eastern part of

[1] It is said that this firm controls over $1,000,000,000 of liquid assets; *Zeitsch. f. angew. Chem.*, 1920, ii., 5.

Oregon. The deposits found in the Amargosa Valley, Inyo County (California), are typical of the United States nitrate deposits. According to the investigation of the Geological Survey, the caliche here forms a layer of an average thickness of 13 cm., about 23 cm. below the surface. The main constituent, apart from sodium nitrate, is sodium chloride. The richest fields would only yield 1,795 tons of nitrate pen 68 hectares if completely exploited.

It has already been mentioned that in the year 1913–14 there was produced in the United States 78,589 tons of nitric acid of various strengths, and 112,124 tons of mixed acid, all from nitrates. These quantities correspond to about 89,000 tons of 100 per cent. nitric acid. For their manufacture there was necessary about 160,000 tons of nitrate, of which the annual imports at that time were 557,000 to 560,000 tons. Towards the end of the War the United States used over 1,000,000 tons of nitrate for the manufacture of nitric acid alone, of which about 650,000 tons of 100 per cent. acid were produced in 1918. Of this quantity, almost five-sixths was used for the manufacture of explosives.[1]

We have already drawn attention to some of the more important improvements in the old method of manufacturing nitric acid with the help of sulphuric acid according to the equation—

$$NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3$$

The old retorts with bottom-firing have now been replaced by new installations reducing the fuel requirements by 25 per cent. Duriron or tantiron (Fe + Si) are now used in the construction of the retort and condensers. The capacity of the condensing towers is thus increased by 40 per cent. The average charge of the retorts has been increased from about 2,250 kg. to about 3,400 kg. The modern retorts are rotary. The newest installations with all these improvements now enable an average yield of 92 to 94 per cent. of the total nitrogen to be obtained, compared with 78 to 80 per cent. formerly; moreover, fewer workpeople are required. The recovery of the waste nitrous gases from various nitrating processes has also been considerably improved.

In the history of the production of nitric acid from the air, the United States holds a position of priority, in so far as it was in that country that the first industrial attempts were made to burn air in the electric arc. In 1902 C. S. Bradley and R. Lovejoy founded the Atmospheric Products Company of Jersey City, N.J. with a capital of $1,000,000 in order to work their process on a large scale [2] (British pat. 8230/1901; U.S. pats. 709,867 and

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 115.
[2] *Chem. Ztg.*, 1902, p. 1018.

709,869; Austrian pat. 12,300; Swiss pat. 24,298). Bradley and Lovejoy utilised direct current of 8,000 volts. Their apparatus proved to be too expensive relatively to the output and too unreliable to ensure definite success. The furnaces were very small. They treated 19·5 cub. m. of air per hour only.[1] The yield was certainly very much better than in previous experiments [2]; at the small plant at Niagara Falls, 1 kg. of nitric acid, of about 50 per cent., could be obtained per 15·4 h.p. hours. It was soon found, however, that the acid and the salts obtained from the same contained nitrous acid and nitrite respectively. The presence of these impurities prevented any considerable utilisation or sale of the products. The Atmospheric Products Company were finally forced to close their plant. This resulted in the disappearance of the United States, for the time being, from the field of atmospheric nitric acid production, and the leadership then passed to Norway and Germany. The problem of the direct production of nitric acid from air was then only studied in experimental plants. Thus, in 1912, the Southern Electrochemical Company, of New York, took up manufacture on a small scale by the Pauling process at their works at Nitrolee (South Carolina).[3] In 1915 the same firm was erecting a plant to utilise 3,000 h.p. at Great Falls, in South Carolina, on the Catawba River; this was to produce 4 tons of acid daily in the first instance. The Du Pont Company, who were the holders of licences for the Birkeland-Eyde process in America, had intended to erect a large atmospheric nitric acid works, but this project was never realised. On the other hand, the American Nitrogen Products Company was founded in 1916–17 at Seattle by the co-operation of individual Norwegians and the Norway Pacific Constructions and Drydock Company, with an initial capital of $750,000, in order to exploit the process of F. H. A. Wielgolaski (German pat. 258,052, 270,758, 272,853, and Norwegian pat. 24,195). The capital of the company, which was mainly contributed from Norwegian sources, was increased to $1,250,000 in 1917, in order to enable the first unit to be erected at La Grande (Washington) in 1917. The Government granted a concession for the development of the large waterfalls at Snohomish County (Washington), which are estimated to represent 230,000 h.p. The first works at La Grande were commenced in the autumn of 1916 and finished in 1917; manufacture was started experimentally in the same year. Only such machines and apparatus were used as had already proved successful in Norway, and the intention was primarily to produce

[1] *Zeitsch. f. angew. Chem.*, 1906, pp. 37–38.
[2] *Ibid.*, 1906, pp. 977 *et seq.*
[3] *Chem. Ind.*, 1912, p. 294.

synthetic nitrates, but also pure ammonium nitrate and so forth. Current was first supplied to the works from the town of Tacoma. The experimental works were only completed early in 1918, by which time the main manufacturing difficulties had been solved, so that large-scale manufacture could be commenced and the product sold to the selling agency, the Marden, Orth and Hastings Corporation, of New York. In this way the new manufacture finally established itself firmly on the west coast of the United States. So far, the main product has been sodium nitrate, of which 1,000 tons have been manufactured per year. In 1918, however, the company decided to extend their works and further develop the available water powers (230,000 h.p.), as the essential conditions for successful working—namely, cheap current and large limestone deposits—were present on a large scale. The War exchanges, which raised the price of sodium nitrate from 45 cents to 110 cents per kilogram, were extremely favourable to the development of the new undertaking. It is intended to erect a works in Canada at a cost of $250,000 with an output capacity of 2,000 tons of sodium nitrate per annum. The production of cyanamide, calcium nitrate and so forth is also intended.

The actual output of all these arc process plants in 1918 amounted to only 2,000 to 3,000 tons of nitric acid, calculated as 100 per cent., so that it was of little account compared to the enormous output figures of other nitrogen fixation plants.

By far the most important private company concerned with nitrogen fixation is the American Cyanamide Company, which was founded in 1907, and which controlled in 1916–17 a capital of $3,250,000 in preference shares, and $2,500,000 in ordinary shares. In 1920 this was increased to $8,000,000 in preference, and $6,500,000 in ordinary shares. The dividends on the preference shares were regularly paid until 1914, but no dividends were paid on the ordinary shares. The company worked the Frank-Caro cyanamide process. The European directors before the War included N. Caro, of Berlin, and E. MacKay Edgar, of London. In 1916–17 permission was obtained to issue a further $12,000,000 of preference shares. The net profits which the company was able to show gives a picture of the wartime conditions. They were namely :—

	$	
(July 1st) 1912–13 (June 30th) . .	189,000	
,, 1913–14 ,, . .	324,000	(Sales, 38,000 tons calcium cyanamide.)
,, 1914–15 ,, . .	58,500	,, 23,000 ,, ,, ,,
,, 1915–16 ,, . .	376,000	,, 42,772 ,, ,, ,,
,, 1916–17 ,, . .	638,000	
,, 1917–18 ,, . .	1,601,410	
,, 1918–19 ,, . .	1,048,752	
,, 1919–20 ,, . .	1,716,360	

If we add the amount carried over from the business year 1917–18, there was available on June 30th, 1919, a total of $1,723,529.

The first cyanamide plant of the American Cyanamide Company started manufacture in 1909–10 at Niagara Falls, Ontario, Canada; in May, 1920, the eight old carbide furnaces were replaced by two new ones. At that time (in 1909–10), the annual output capacity was 12,000 tons; nitrogen was produced from the air by the old copper oxidation process, which was replaced by the rectification of liquid air at the commencement of 1917. The plant was enlarged in 1912–13 to an output capacity of 32,000 tons per annum and in 1913–14 to 64,000 tons per annum. In 1919 the whole plant was working at its maximum capacity. In 1914–15 80 per cent. of the total production was still sold in the form of cyanamide, and only a very small portion was further transformed into ammonia, urea and cyanide. When discussing the development of the German nitrogen industry, we already mentioned that W. S. Landis, of the American Cyanamide Company took part in various meetings of the Frank-Caro interests, and that he used the opportunity to inform himself exactly on the decomposition of calcium cyanamide in autoclaves. As a consequence, already in the first month of 1915, a similar plant was erected in the United States, in the first instance on a small scale. In 1916–17 the American Cyanamide Company acquired the whole share capital of the Ammo-Phos Corporation, which was operating a newly erected plant for the manufacture of ammonium phosphate on the New Jersey coast of New York Harbour. By means of an affiliated company, the Amalgamated Phosphate Company, the parent company also entered into close relationship with the Virginia-Carolina Chemical Company, and thus became a member of the Association of Phosphate Exporters of Florida. The demand for ammonia rose steadily during the War, so that finally, in 1917, an agreement was signed with the Government, according to which the company undertook to supply their whole production of synthetic nitrogen in the form of ammonia only. In order to fulfil these conditions, both the cyanamide decomposition plant at Niagara Falls and the Ammo-Phos Works at Warners, New Jersey, were considerably enlarged. In the second half of 1917 the demand for ammonia increased still further, and could only be met by improvement in the plant. In 1919 the production of NH_3 was 14,728 tons. At the close of 1917 and the commencement of 1918, the normal production at Niagara Falls was impeded by unjustifiable withdrawal of electric supplies by the Ontario Power Company. These conditions were only improved towards the end of April, 1918. The production from calcium cyanamide of a low-grade cyanide particularly suitable

for the extraction of gold was further improved in 1917. One of the large American mining companies utilises this product. Since 1917 urea compounds have also been sold. The trade in these products was, however, hindered from the summer of 1917 to December, 1918, by the agreement with the Government already referred to. The American Cyanamide Company also manufacture argon as a by-product, which is utilised for filling electric lamps and for similar purposes.

The Ammo-Phos Works at Warners, N.J., were primarily intended for the manufacture of ammonium phosphate, which was placed on the market under the registered name of "Ammophos," and contains 13 to 20 per cent. of ammonia and 47 per cent. of phosphoric acid, mainly in water-soluble form. They obtained calcium cyanamide from Niagara Falls, and at that time decomposed it in autoclaves, which had a daily output of 30 tons of NH_3 gas. At Niagara Falls their own cyanamide has been treated since 1915, first on a smaller, and then on a larger scale, but the Warners plant is still supplied as before with cyanamide from outside, which is converted by them at that plant into ammonia. In 1916 there was erected at Warners the first American works installation for the catalytic oxidation of ammonia. The process used by them was due to Landis and depends on passing a mixture of gaseous ammonia and air from below through a net of platinum gauze and cooling it just before it passes through the catalytic zone. (In the Frank-Caro process the gases are passed through the gauze net from above.) The first plant at Warners comprised six catalyst units, of which each was to produce 6·4 kg. of nitric acid per hour. By means of various improvements, this output was increased to 18·1 kg. of nitric acid per hour. The catalyst is a fine, electrically heated layer of platinum wire gauze with a surface of about 1,858 sq. cm. Two such elements supplied the nitric acid requirements of sulphuric acid chambers, of a capacity of 60,000 tons per year, for two years. The ammonia which is oxidised is obtained directly from the autoclaves in which the calcium cyanamide is decomposed, each of which supplies 30 tons of ammonia gas per twenty-four hours. The demand for ammonium phosphate in 1920 was very large.

The sulphuric acid produced by the Ammo-Phos Corporation was partly used for the decomposition of the phosphate necessary for the production of ammonium phosphate. Another portion was utilised for converting the ammonia from cyanamide directly into ammonium sulphate. When the agreement between the American Cyanamide Company and the American Government came into force in the summer of 1917, the manufacture of ammonium phos-

phate and ammonium sulphate was stopped. Apart from ammonia, only small quantities of nitric acid were produced for use within the works. The total production of the sulphuric acid works was also absorbed by the Government for the decomposition of nitrate, which in turn served for the manufacture of ammonium nitrate. On the conclusion of the truce these deliveries of ammonia and sulphuric acid ceased. It was possible rapidly to resume the manufacture of ammonium phosphate and ammonium sulphate at Warners, N.J., as new and ample markets were quickly found, both in the States and abroad. The production of phosphate rock at Brewster, Florida, once more increased; thus, by the commencement of May, 1919, the deposits were again being fully worked; in this month a strike interfered very seriously with the production for a time. The prospects for the export of phosphates are considered to be very favourable. The losses of the Amalgamated Phosphate Company in 1917–18 were \$164,000.

In 1919 the American Cyanamide Company at Niagara Falls and Warners produced less cyanamide than ammonia, ammonium salts and cyanides. An agreement which came into force on December 1st, 1919, fixes the cyanide prices for ten years at the manufacturing cost plus 20 per cent. The agreements for phosphate deliveries are also for long periods, and at the end of November, 1919, the company was faced with unfulfilled orders to the amount of \$4,430,000, so that the position is very favourable.

The Ammo-Phos Corporation also manufactures concentrated ammoniacal liquor. Recently it has also been supplied with cyanamide from Muscle Shoals. The residues from the decomposition of calcium cyanamide are also sold to farmers under the name of "soilime." This product contains 50 per cent. of CaO, mainly in the form of carbonate and hydroxide.

In the second half of 1917 the Air Nitrate Corporation was founded as an agent for the American Government in the erection of plant for the manufacture of ammonium nitrate by means of the cyanamide process. The total capital of the Air Nitrate Corporation, which is only nominal, belongs to the American Cyanamide Company, which granted a licence for the use of its patents. The Government pays the Air Nitrate Corporation a consideration for the erection and administration of the Government works.

The Southern Power Company, of Chester, took up the manufacture of calcium cyanamide for a time in an experimental works in 1912.[1] There was at that time another smaller experimental plant in Baltimore. It has lately been proposed that the

[1] *Chem. Ind.*, 1912, p. 294.

gas wells of the Fraser Valley in British Columbia, which produce almost pure nitrogen, should be utilised for the manufacture of cyanamide; the project would be simplified by the fact that large power resources are available on the Pacific coast, for example at Stave Lake.

In the United States the Union Carbide Company, the former owner of the Willson patent, made such advantageous trade agreements that they hold a monopoly of carbide manufacture. They have latterly united with the National Carbon Company and the Carbide Air Reduction Company. The main works are at Niagara Falls and Sault Ste. Marie, Michigan, and before the War produced about 80,000 tons of carbide, of which about 10,000 tons were exported to South America. In 1914 15 the total carbide export was 16,000 tons, and 17,000 tons in 1915 16. As the costs for power and labour are cheaper in Norway than in the United States, the Union Carbide Company erected a third large works at Saude in Norway. The consumption of cyanamide in the United States increased between 1911 and 1916 from 5,000 to 40,000 tons.

In the spring of 1916 the American Cyanamide Company erected the first electrically heated (Landis) contact unit for the oxidation of ammonia from cyanamide at Niagara Falls, Ontario. In the same year, but several months later, the first manufacturing plant was started at Warners, N.J. The Ostwald-Barton process of the English Nitrogen Products and Carbide Co., Ltd., did not come into permanent use in the United States in its original form. At the suggestion of Chas. L. Parsons, the Semet-Solvay Company, of New York, and the Bureau of Mines, were requested by the Government on August 10th, 1916, definitely to discover whether coke-oven ammonia could be oxidised on a manufacturing scale or not. To decide this question a small experimental plant was erected at Syracuse, N.Y. Although laboratory experiments carried out by the Bureau of Mines in conjunction with the Semet Solvay Company had shown that other metallic and non-metallic catalysts could be utilised instead of platinum. it was finally decided to continue to use spirally rolled platinum gauze. Electric heating was dispensed with entirely. The construction proved so satisfactory that Brunner Mond & Co., Ltd., England, also erected a Jones-Parsons unit for experimental purposes, and the American Government Plant No. 2 at Muscle Shoals was mainly furnished with ammonia oxidisers according to this system. The plant of the Semet Solvay Company at Syracuse was later enlarged, until the daily production amounted to several tons of nitrate and nitrite. In spite of attempts to introduce it, the Serpek process attained no importance.

The Air Nitrate Corporation erected No. 1 Government Plant at Sheffield, Alabama, with a maximum output capacity of 15,000 tons of 100 per cent. nitric acid per annum. The plant utilises Landis units of the American Cyanamide Company. There are six oxidation sheds, each containing four rows, each of 29 units—that is, 696 units in all. Each unit contains 143 gm. of platinum. As the plant manufacturing ammonia was unsuccessful, Sheffield was unable to deliver ammonium nitrate during the War. At a later date 15,000 lb. of the nitrate were manufactured from ammonia from other sources.

Muscle Shoals is said to produce 90,000 tons of 100 per cent. nitric acid annually. A small plant in Long Island city is also said to use the platinum gauze oxidation process.

The maximum output capacity of all contact plants completed or on the point of completion in the spring of 1919 is stated to have been 225,000 tons of 100 per cent. nitric acid. As 650,000 tons of HNO_3 are annually produced in the United States from Chile nitrate (see p. 264), the total output capacity of all plants would be not less than 875,000 tons of 100 per cent. nitric acid. This output would be more than nine times as large as the demand before the War. In 1913–14 the explosive industry utilised about [illegible],000 tons, whilst about 40,000 tons were used for all other purposes. Even if the consumption of the American dyestuff industry is estimated at 30,000 to 40,000 tons of HNO_3 per annum, the peace demand would only be 120,000 to 130,000 tons. As the output capacity is almost seven times as large as this figure, the production of nitric acid would have to be very considerably reduced, even though large amounts of acid were used for the manufacture of nitrate fertilisers.

In a lecture at the Exhibition of the American Chemical Industry (see p. 261), E. J. Pranke discussed the future prospects of ammonia oxidation processes in U.S.A. in detail,[1] comparing, more particularly, the economic results with those of the older processes. It is very difficult to make definite prophecies on this matter. "The cost of converting sodium nitrate into concentrated nitric acid is approximately as high as the manufacture of nitric acid from gaseous ammonia from autoclaves. Gaseous ammonia is certainly a cheaper form of nitrogen than sodium nitrate. It is cheaper by the cost of the sulphuric acid, which is necessary for the fixation of the gaseous ammonia in the form of ammonium sulphate; for sodium nitrate and ammonium sulphate were formerly approximately equal in price per kilogram of nitrogen. (Thus, for example, in Germany in 1913 1 kg.

[1] *Chem. Trade Journ.*, No. 1642 (1918), pp. 341–342; *Zeitsch. f. angew. Chem.*, 1919, i., 115–116.

of nitrogen in Chile nitrate f.o.b. Hamburg cost 138 pfg.; 1 kg. of nitrogen in ammonium sulphate f.o.b. Hamburg cost 138·2 pfg.) Should a difference in these prices occur at a later date, the price in the form of ammonia will probably be lower. The difference between the prices for ammonia gas and ammonium sulphate will make a difference of about 15 to 20 per cent. in the price of nitric acid, in favour of the ammonia oxidation process. The fact that those works which manufactured nitric acid from Chile nitrate during the War have written off the cost of plant and have this advantage under peace conditions, whereas new oxidation plants must first be built in the same localities in order to avoid high transport charges, has an unimportant influence only on the price position, as amortisation charges represent about 4 per cent. only of the normal price of nitric acid. The question whether there is sufficient initiative in America for the development of the new industry will be decisive for the success of the new process."

At the outbreak of war the position of the nitrogen industry was rather indefinite in America. As interest in the synthetic production of nitrogen compounds gradually increased, the Government undertook the definite investigation of the competing processes in an admirable fashion. A special commission for nitrate supplies was formed, of which A. N. Noyes, L. H. Baekeland, G. Dunn, Ch. H. Herty, W. K. Lewis, M. J. Pupin, T. W. Richards, E. Thompson, and W. R. Whitney were members. The commission sought the assistance of further experts, among whom Chas. L. Parsons, the chief chemist of the Bureau of Mines, especially distinguished himself. In 1916 Parsons undertook a journey in order to study the English, Italian, French, Norwegian and Swedish nitrogen works, so that he might critically compare the advantages and disadvantages of the various processes. He made his first report on January 27th, 1917,[1] in which he comes to the conclusion that the annual requirements of the Government for the manufacture of munitions amounted to 20,000 tons of nitric acid per annum in peace time, and 180,000 tons per annum in war time.

Parsons naturally first directs attention to the conversion of by-product ammonia into nitric acid, which is the most practicable method of supplying American requirements. We will consider very briefly the very reliable data of Parsons on the various groups of processes. The arc processes are not used on a large manufacturing scale anywhere, except in southern Norway, which

[1] *Chem. Trade Journ.*, October 13th and 20th, 1917, pp. 299–301; *J. Ind. Eng. Chem.*, September, 1917, pp. 833–839; Hesse-Grossmann, "Englands Handelskrieg und die Chemische Industrie," vol. iii. (Stuttgart, 1919), pp. 75–98.

utilises for this purpose 250,000 h.p. In that locality the cost of a horse-power year is less than 20 marks (£1). Even at a cost of 40 marks (£2), the acid which is produced could still compare in price with that produced by other processes. Concentrated nitric acid can, however, only be transported in aluminium tank waggons, or in iron tank waggons when mixed with sulphuric acid. It is unsuitable for the manufacture of fertilisers, as neither the calcium nor the ammonium salt can readily be used in certain mixed fertilisers which are demanded by American agriculturalists. On the assumption that the yields which are obtained are as good as those in Norway, the arc process requires 2·33 h.p. years per ton of dilute nitric acid. In order to supply the peace demands of the American Government, 50,000 h.p. at least would therefore be necessary, whilst in war the necessary amount would be 440,000 h.p. In practice these minimum figures would be raised to 75,000 and 555,000 h.p. respectively. It would be advisable to unite the production of arc nitric acid in the same works with the manufacture of explosives, and the locality should be chosen with due regard to the freight charges for benzene, toluene, alcohol, glycerine, acetone, sulphuric acid, cotton, etc., and to the convenient transport of the explosives. An arc plant which would be sufficiently large to supply with certainty the demand of the American home requirements in war time would have to be closed for the greater part in time of peace.

In Parsons' report the Haber-Bosch process is stated to be the cheapest of the fixed ammonia processes which were then practised. One pound of liquid anhydrous ammonia is stated to have been manufactured in Germany before the War for 4 cents. One of the main elements of the cost is the manufacture and purification of the hydrogen. "The technical control of the Haber process required so great an experience and degree of skill that if the present directing forces of the B.A.S.F. were lost, many months would be required in order to replace them by other leadership, equally capable of technical direction of the process. At the present time the process is not practised outside Germany in consequence of lack of experience with regard to the plant and method of working, and of the large royalties which are demanded by the B.A.S.F. It appears more than probable that after the end of the War the B.A.S.F. will work this process outside Germany. The process is independent of cheap power, as the power costs are unimportant."

The cyanamide process requires cheap power. It only requires one-fifth of the power per ton of fixed nitrogen which is required by the arc process. At a power cost of approximately 33 to 34 marks (£1 13*s.* to £1 14*s.*) per horse-power year, the production cost of

ammonia from cyanamide would amount to 1 to 2 cents (½*d.* to 1*d.*) per pound more than by the Haber process. As, however, the licences are very much more favourable in this case, and there are sufficient experienced engineers and experts who can erect such a plant, the calcium cyanamide industry might at that time be considered to offer the most favourable prospects. "If an electric power station were built by the Government of the United States, and the power were used for the fixation of nitrogen, the cyanamide process would present advantages over all other processes so far practised, and should therefore be accepted as the best process for the fixation of nitrogen when using electrical energy from water power." "Ground cyanamide is a very dusty, unpleasant product and must be treated with oil or by a special granulation process in order to be used as a fertiliser. By these means the dust-producing properties of the product are considerably reduced."

"Cyanamide has not been received with favour by American users, in spite of its good fertilising qualities; moreover, it is on the whole relatively unsuitable for addition to mixed fertilisers, such as are required by American agriculturalists. In Europe it can be utilised more successfully, as the cheap cost of labour enables the European farmer to spread each fertiliser on his field unmixed and at the proper time. In order to supply 20,000 or 180,000 tons of nitric acid respectively, 11,000 or 99,000 h.p. respectively must be available for the cyanamide industry." "If cyanamide is to be converted into ammonium sulphate, then the cost for the conversion of the nitrogen into ammonia before absorption in sulphuric acid amounts to about 1 cent. per pound. The necessity of converting calcium cyanamide into ammonia if nitric acid is ultimately to be produced, is largely responsible for the difference in the production costs between the calcium cyanamide and the Haber-Bosch processes."

The production of ammonia or its salts as by-products of the coking industry is of exceptional economic importance. The quantity of ammonia which has been obtained from this source in the United States during the last two years has increased to a degree which would have been considered impossible a short time ago (see p. 288). By the end of 1917 115,000 tons of ammonia, equivalent to 450,000 tons of ammonium sulphate, will have been produced during the year. For military purposes, 6,000 tons in peace time and 55,000 tons of NH_3 in time of war would be sufficient. In the twelve to thirteen months preceding January, 1917, more than $50,000,000 of new capital was invested in by-product plants. Ammonia from coke-oven gas must always be purified before it can

be further oxidised to nitric acid. The costs of such purification are very small. In cases where purification plant was installed in conjunction with the original ammonia absorption plant, the cost represents only a fraction of a cent per pound, compared with the production costs for crude ammoniacal liquor. The main impurities removed are CO_2, H_2S, and HCN. Oxidation units are readily attached to existing by-product plants, and as these latter are distributed over various parts of the country there would be a considerable advantage from the standpoint of military defence in the lack of centralisation. On the other hand, the utilisation of by-product ammonia for oxidation to nitric acid suffers from the great disadvantage that the sale price of ammonia is itself high. The use of ammonia would, therefore, hardly be practicable if special price concessions were not made to the Government. The conditions are more favourable for ammonia from cyanamide or produced by the Haber process, as these would be manufactured in special Government plants, in the erection of which purposes of national defence would be the prime consideration. The present cost of pure ammonia as a by-product of the coking industry is, however, much lower than the cost by any other process.

The very interesting cyanide process (see p. 287) is only discussed in Parsons' second report of April 30th, 1917. In the first report he merely mentions that it should be possible to produce fixed nitrogen more cheaply by red-hot mixtures of soda, coke, and so forth, than by the known synthetic methods. Small plants were already operating this process in 1916–17, but the mechanical difficulties of large-scale manufacture still remain to be overcome. The American mining industry would always provide a market for cheap cyanide.

Ammonia oxidation processes were first used in the form developed by Landis of the American Cyanamide Company at Niagara Falls and at Warners, and of the Ostwald-Barton process of the Nitrogen Products and Carbide Company. According to Parsons this latter process was, in 1916–17, undoubtedly superior to any competing methods, including the German Frank-Caro method, with regard to economy and importance.

"By the oxidation of ammonia, nitric oxide is obtained at a far greater concentration than by the arc process. Consequently, a much smaller surface is necessary for absorption in the towers, in which a much stronger acid can immediately be obtained. When the arc process is used, tower acid of 30 to 35 per cent. HNO_3, corresponding to 22·5° to 26·0° Bé., must be concentrated, whilst by ammonia oxidation, tower acid of 50 to 55 per cent. HNO_3, or 34·6°

to 37° Bé. can be obtained, the further concentration of which is relatively simple."

Parsons also gives certain details regarding a method developed in Sweden, according to which ammonia or cyanamide is oxidised in solution to ammonium nitrate, which is then obtained as such by evaporation of the electrolyte, or may be converted into nitric acid. He is unable to give details with regard to the process. A plant was to commence manufacture near Gothenburg in the summer of 1917, and another larger works was erroneously said to be projected in the neighbourhood of Berlin.

It is impossible to discover the basis of this information. In any case, no large plant near Berlin was built. There is nothing new in the fact that ammonia can be oxidised to ammonium nitrate under certain conditions, as such electric oxidation has already been described by E. Müller, Spitzer, Brochet, Boiteau and others.[1]

Parsons finally concludes that for America "the most important problem is to ensure a sufficient reserve of nitrate, and for that purpose to arrange for the control of the most suitable method of oxidising ammonia and to train the necessary staff for the erection of such plant and for the proper control of all operations in such ammonia oxidation plants."

"The cost of nitric acid itself, apart from its concentration, is lowest when the arc process is used, if water power is available at a cost of not more than 40 marks (£2) per horse-power year. The transport difficulties, the large power requirements, and other economic reasons make this process unavailable under American conditions."

The cost of nitric acid manufacture by the oxidation of ammonia depends on the production cost of ammonia itself. This is at present in no sort of relation to the sale price. The working costs of recovering and purifying ammonia from coke-oven gases are lower than those by any other process. The sale price of this by-product ammonia is entirely independent of competition with other nitrogen compounds, and has therefore in the past been almost entirely controlled by the price of Chile nitrate. "Even though ammonia produced by the Haber process were marketed at a price of 4 cents per pound, it would still be possible for the producers of by-product ammonia to sell this at a profit. The cost price is in this case merely a question of book-keeping. The sale price will in the future, as in the past, depend on the competition by other nitrogen compounds. By the Haber process synthetic ammonia can be more cheaply produced

[1] *Zeitsch. f. Elektrochem.*, 1905, p. 917; *Ber.*, 1906, p. 166; *Zeitsch. f. Elektrochem.*, 1906, p. 937; *Chem. Ztg.*, 1909, p. 629.

than by any other synthetic process, and this is already being done. The cyanamide process takes the second place. Should the mechanical difficulties which have still to be overcome be solved, the cyanide process (January, 1917) would provide ammonia more cheaply than is possible by the Haber or cyanamide processes. Thus the possibility of competing with by-product ammonia is assured."

When Parsons wrote his first report on January 27th, 1917, he was convinced that the Haber and cyanide processes would sooner or later be introduced in America, and that it would therefore be unwise to devote large sums to the expensive arc or cyanamide processes. He therefore arrived at the conclusion that the ammonia oxidation plants should be extended and that sufficient stocks of Chile nitrate and platinum should be acquired.

The development of the nitrogen industry in the United States was then so rapid that on April 30th, 1917, Parsons found it necessary to make a second report to the Government.[1] Meanwhile the ammonia oxidation plant at Syracuse had worked very satisfactorily, and successful attempts had also been made at Laurel Hill to replace platinum by other contact materials. Still greater successes were reported by the General Chemical Company, the work of which Parsons describes in detail This latter company had been occupied since 1913 with the development of a synthetic ammonia process directly from the elements, similar to that of Haber. In April, 1917, an experimental plant operating their process was fully active. The General Chemical Company were prevented from immediately erecting a large plant by the extraordinarily increased costs of building materials and other difficulties. Their President, William H. Nichols, offered to hand over the plans and experimental results to the American Government. Detailed consultations followed between him, the Bureau of Mines, and the Ministry of War in April, 1917, in consequence of which the General Chemical Company gave their results to the Government confidentially, free of cost, and promised their co-operation in the erection of works. Two projects were submitted, one for a plant for the manufacture of 27 tons of NH_3 daily, and the other for an output of only 6·8 tons daily. The general opinion was that the 27-ton plant could be erected at a cost of $3,000,000. The manufacturing cost of ammonia was estimated to be less than 4 cents per pound, if $5 per ton was allowed for repairs and 12½ per cent. of the installation cost for interest and amortisation. The outgoings for repairs, interest, and amortisation were estimated at 50 per cent. of the cost price of the ammonia;

[1] *J. Ind. Chem.*, **9**, 839–884 (1917).

overhead charges and other expenses were estimated at a further \$3 per day. In 1917 the small 6·8-ton plant was estimated to cost \$1,100,000, including land and buildings, and to be capable of supplying annually 2,450 tons of NH_3, or 7,900 tons of 96 per cent. nitric acid at a conversion yield of 85 per cent. The power requirements were estimated at about 500 h.p.

On the basis of the project supplied by the General Chemical Company, which incidentally had been in relation with the B.A.S.F. before the War, Parsons made the following proposal to the Government; he proposed that the Government should decide on the construction of the 27-ton plant, for which the War Ministry should supply \$3,500,000 and conclude an agreement with the General Chemical Company, according to which a royalty per ton of fixed nitrogen should be paid to the General Chemical Company on that portion of the ammonia only which the Government did not wish to utilise for its own purposes, but decided to sell. He recommended that the new works should be erected in the neighbourhood of the sulphur and coal mines of South-western Virginia, or in the neighbouring district of West Virginia.

Parsons' report also discusses the cyanide process of J. E. Bucher (p. 287), on which Edward E. Arnold, President of the Nitrogen Products Company, reported very favourably. In 1917 the Nitrogen Products Company were running two experimental plants, one at Saltville, Virginia, working with a coal-fired furnace, and the other at Niagara Falls, with an electric furnace. Both plants were inspected by a Government commission in April, 1917. The Nitrogen Products Company offered the cyanide process to the Government for its own use on the same conditions as those of the General Chemical Company. Parsons considered it necessary to advise that a large plant should not be built at the moment, pending the result of further experiments. He recommended that such experiments should be carried out by the Government on a large scale at a plant to be built at Saltville, Virginia, at a cost of \$200,000.

As a conclusion to his report, Parsons gives an estimate of the installation and working costs of the various processes in 1917. The table is reproduced on p. 279, with the original figures, which refer to 1 ton of nitrogen.

The relative costs of the various nitrogen processes were also discussed by F. S. Washburn, W. S. Landis, E. Kilburn Scott [1] and others. Kilburn Scott gives the following figures for the total yield per kilowatt year (1 ton of coal = 1,500 to 1,600 k.w.h.):—

[1] Lectures before the American Chemical Society and the Society of Chemical Industry. *J. Soc. Chem. Ind.* 1917, p. 771; *Chem. Ztg.*, 1915, p. 643; 1916, p. 971.

Kilburn Scott's figures.

(*a*) *Arc Process.*—One kilowatt year yields 130 kg. of fixed nitrogen.

(*b*) *Cyanamide Process.*—One kilowatt year yields 380 kg. of fixed nitrogen.

(*c*) *Haber Process.*—One kilowatt year yields 830 kg. of fixed nitrogen.

Parsons' figures (per ton Nitrogen).

Product.	Arc Process 35 per cent. HNO_3.	Cyanamide Ammonia.	Haber Process 35 per cent. NH_3.	General Chemical Company. NH_3.[1]
Power requirements in horse-power	10·5	2·2	0·2	0·2
Capital outlay	1,420[2]	440[2]	540	300
Production cost in dollars[3]	170	150[4]	119	97
		96 *per cent.*	*nitric acid.*	
Required power in horse-power	10·8	2·3	0·3	0·3
Capital required[5]	1,550	670	570	520
Production cost in dollars[6]	220	270	239	217

The arc process yields 600 kg. of nitric acid per kilowatt year, equivalent to 130 kg. of nitrogen; the cyanamide process requires 2 kw. years of electrical energy per ton of fixed nitrogen, and 3 to 3·5 tons of coal; and the Haber process requires, for the same quantity of nitrogen, 6·5 to 7 tons of coal, inclusive of the amounts required for the production of the necessary hydrogen and nitrogen. Landis summarises the fixation capacities of the works in all countries as follows:—

	1913. Tons N.	1915–16. Tons N.
Cyanamide plants	59,490	190,000
Arc plants	16,915	27,570
Synthetic ammonia plants	7,300	54,430
Total	83,705	272,000

[1] The estimates of the General Chemical Company are based on constructional costs in 1917; the other figures are based on normal prices.

[2] The power plant is here assessed at $100 per horse-power.

[3] The amortisation for the calcium cyanamide process is based on the data supplied by various companies; for the Haber process 20 per cent. of the installation cost is allowed for repairs, interest, and depreciation. Amortisation for the arc process and modified Haber process is estimated at 12 per cent. for interest and depreciation, plus $5 per ton for repairs.

[4] $122 for cyanamide manufacture, plus $28 for ammonia manufacture.

[5] Excepting in the case of the arc process, an ammonia plant is here included in the calculations. The additional charges are $10 for power, $140 for oxidation and absorption, $40 for concentration, and $40 for the steam-raising plant.

[6] Excepting in the case of the arc processes, these figures also include costs for the ammonia plant. $50 is allowed for ammonia oxidation, and $70 for concentration. The cost of the unoxidised ammonia was not included.

According to Landis and Washburn, in order to produce 180,000 tons of concentrated nitric acid there are required 540,000 h.p. of electrical energy and $80,000,000 installation cost by the arc process, and only 100,000 h.p. and $30,000,000 by the cyanamide process, the installation cost per horse-power being assumed to be $100. In the United States in 1916–17 1 h.p. year from water-power cost $12 to $20 as against $3 to $6 in Norway. For this reason the Union Carbide Company acquired water powers in Norway. Most of the large and cheap water-powers in the United States were acquired in 1917 by the Aluminium Company of America.

The reports of Charles L. Parsons, which display very exceptional expert knowledge, became the basis for the establishment of the Government Nitrogen Industry in America. Charles L. Parsons meanwhile retired from his position as chief chemist of the Bureau of Mines in order to devote himself completely in the future to his duties as Secretary of the American Chemical Society.[1]

In 1916 the Norwegian engineer, Eystein Berg, also studied the processes of the European nitrogen industry on behalf of the United States Government. In the second half of 1917 the Air Nitrate Corporation was formed as a company affiliated to the American Cyanamide Company, and was commissioned by the Government, which advanced it $20,000,000 in the first instance, to erect and control plant for the production of cyanamide and ammonium nitrate. It was decided to build three Government works, of which one was to be at Muscle Shoals on the Tennessee River, North Alabama, a second at Cincinnati, Ohio, and a third at Toledo, Ohio. In 1917 the erection cost for all three works was estimated at $75,000,000, and the works had been, or were to be taken over by the Government. The experience of the Cyanamide Company was fully utilised. As already mentioned, this company had commenced in the spring of 1915 to convert considerable quantities of cyanamide into ammonia, and further into ammonium nitrate, and carried out these processes later, in 1917–18, on a large scale. The patents relating to the decomposition of calcium cyanamide were all controlled by the American Cyanamide Company. It was absolutely clear from the plans submitted to the Ordnance Department in 1917 that it should be possible to erect large works to operate the cyanamide process within twelve months. The erection costs constituted a fraction only of the amount necessary for the extension of the necessary coke-oven by-product plants. The first plant, the erection of which was commenced, was the U.S. Nitrate Plant No. 2 at Muscle Shoals. Westinghouse, Church, Kerr and Company erected the power plant,

[1] *Chem. Ztg.*, 1920, p. 36.

whilst the Chemical Construction Company supplied the bulk of the chemical plant. Muscle Shoals was chosen as a locality for the plant, as it was sufficiently far from the coast to be safe from hostile attack. From the transport standpoint the locality is very favourable, both for the supply of coal and coke, and also for the marketing of products in the form of fertilisers in time of peace. The most important factor was the possibility of utilising the water-power of the Tennessee River, capable of supplying 90,000 kw. normally and 180,000 kw. as a maximum. The available power could be increased to 500,000 kw. by the erection of a dam, but, as this would have taken four to five years to construct, a special steam-power station and a ring transmission line to the works of the Alabama Power Company were supplied which would be useful as a reserve later. The neighbouring towns of Sheffield, Florence, and Tuscumbia had only 10,000 inhabitants jointly. A complete town of barracks was therefore erected to house the 20,000 workpeople employed in construction, and the erection of a permanent colony for 12,000 inhabitants was commenced on an area which had formerly been devoted to cotton planting.

The erection of the works was definitely decided on November 16th, 1917; on December 20th, 1917, the first deliveries of material were made; on February 16th, 1918, the first sods were removed, and on November 25th, 1918, the first ammonium nitrate was manufactured. Current had at first to be obtained from the Alabama Company, as the works power station was not yet finished, and a large portion of the works had not yet attained its maximum output.

The works lie 35 m. above the level of the river, excepting the power station, which lies in a hollow 11 m. above water level. The coal trucks enter the boiler house above and the ashes can be withdrawn below and utilised for levelling the site. The works are divided into the following sections, each of which has its own offices, stores, laboratories, and so forth :—

(1) The power station.
(2) Preparation of raw materials for carbide manufacture.
(3) Carbide furnaces.
(4) Carbide grinding mills.
(5) Nitrogen plant.
(6) Cyanamide manufacture.
(7) Cyanamide grinding mills.
(8) Ammonia production.
(9) Nitric acid manufacture.
(10) Ammonium nitrate manufacture.

Various details will be further described in the technical portion of this book.[1] By November 15th, 1918, the constructional costs had amounted to $18,600.000, but the works were not yet finished. By November 15th, 1918, 34,000 men were employed. The output is 110,000 tons of ammonium nitrate per annum, equivalent to about 90,000 tons of 100 per cent. nitric acid ; no further considerable quantities of nitrate were, however, delivered before the conclusion of the truce.

At the conclusion of the truce plans were ready for three further plants, of which two were to supply the Army, and were to be built at Cincinnati and Toledo, Ohio. Each of these plants was to have had half the output capacity of Muscle Shoals. It was planned that the works at Cincinnati should be built first at a cost of $25,000,000. These plans were not carried out. The Admiralty intended to instal a plant at Indian Head, Maryland, to produce 30,000 tons of nitric acid per annum by the process of the General Chemical Company ; this plan was also dropped.

As a result of the report supplied by Ch. L. Parsons to the Nitrate Supply Committee of the War Department (pp. 272–280), $20,000,000 was placed at the disposal of the General Chemical Company for the establishment of an ammonia works using their modified Haber process ; this was done even before the erection of the Muscle Shoals plant was decided on. The General Chemical Company's plant was known as U.S. Nitrate Plant No. 1, Sheffield, Alabama ; it was intended for an output of 22,000 tons of NH_3 per annum, and cost $3,000,000. The process met with so many difficulties that it had to be stopped after operating for a very short time, including several useless experiments. No ammonia whatsoever was supplied by the plant. At the commencement of 1919 it was decided to despatch a commission of experts to Germany to acquaint themselves with the details of the working of the Haber-Bosch process at Oppau in the occupied area, so that this might be transferred to America. Apart from the synthetic ammonia plant, there is also at Sheffield a large ammonia oxidation plant with an annual output capacity of 15,000 tons of 100 per cent. nitric acid which utilises the Landis catalyst of the American Cyanamide Company. The elements contain unheated catalysts consisting of several layers of platinum gauze rolled into cylinders which are welded together at various points. With these platinum contacts a velocity of the ammonia air mixture can be maintained which is several times higher than when electrically heated contacts

[1] See *Chem. and Met. Eng.*, 1919, p. 9 ; *Electr. World*, 1919, pp. 677, 729 ; *Chem. Zentralbl.*, 1919, ii., 836–837.

are used. The reaction is first started by heating, and then maintains itself. Nitrate Works No. 1 was producing in 1918, but the oxidation plant had to utilise ammonia from elsewhere, as no ammonia could be produced in the works.

The American Government has so far invested a total of \$116,000,000 in the nitrogen industry. It originally intended to carry all the proposed plans to completion, in spite of the conclusion of peace, so that agricultural interests might be supplied with fertilisers, but this plan was departed from in December, 1918. Since that date Plants 1 and 2 only have maintained production, but not continuously. It was found that at Muscle Shoals the production cost of ammonia in 1918 was 16·7 to 17·0 cents per pound, when power was obtained from coal, or for 13·0 cents per pound when water-power was used. These figures do not, however, allow for any amortisation of the capital cost. This amounted to about \$30,000,000, which figure includes the cost of land, housing, and so forth. The normal sale price of ammonia in 1918 was fixed at 24·0 cents. At the request of the War Department, the United States Department of Agriculture also experimented on the Haber ammonia synthesis at their agricultural station at Arlington in Virginia. These experiments are said to have given good results.[1]

At the end of 1919 Senator Wadsworth proposed in Congress that a central office for the nitrogen industry should be established, with research laboratories and so forth, as a precaution in case of war. Early in 1920 a Bill of much wider scope was submitted to the Senate and the House of Representatives by the War Department. The proposal was to establish a United States Fixed Nitrogen Corporation for the fixation and utilisation of atmospheric nitrogen for military, agricultural and industrial purposes. It was proposed that the necessary funds should be supplied entirely by the Government. The purpose of the company is to build, direct, and extend the Government nitrate plants at Sheffield and at Muscle Shoals. It was proposed that it should acquire under the same conditions the research laboratories at Washington, the Waco limestone quarries at Alabama, and the Warrior River electric power station of the Alabama Power Company. The water-power plant at Muscle Shoals was also to be handed over to the company on completion. The company was also to acquire related patents and processes, and to export any surplus production which it might be impossible to dispose of in the United States.[2] The intention of the Government to utilise their nitrogen plant in this manner and to manufacture

[1] *Umschau*, 1919, p. 7.
[2] *Chem. Ztg.*, 1920, p. 204.

fertilisers, more particularly ammonium sulphate, elicited very lively protests from the American fertiliser manufacturers.[1] They defended their standpoint by the following considerations :—

"The utilisation of the electric turbine power plant of 120,000 h.p. at Muscle Shoals and the extension of the Wilson Dam power station at that locality to supply in the first instance 100,000 h.p., and later 275,000 h.p., for the manufacture of fertilisers from atmospheric nitrogen would constitute unfair competition on the part of the Government, as the Government works are supported by the community, and do not therefore have to write off sums for depreciation, interest, and so forth, as is the case with private undertakings; moreover, they would be free from all taxation. Apart from this, the market is in any case sufficiently supplied with ammonium sulphate, and in the future it would be possible to obtain such quantities in Europe as were needed in America. Therefore it is a waste of money further to develop the power station. The Government should content itself with accumulating such stocks of Chile nitrate as might be necessary for war contingencies. Instead of damaging the private fertiliser industry, which employed a capital of over $300,000,000 in 1919 and had an output of 7,000,000 tons, by anti-capitalistic legislation, the Government should rather assist the development of the same."

Just before the close of the War the works at Muscle Shoals were producing 270 tons of ammonium nitrate daily. The ammonium nitrate works at Perryville, Maryland, built by the Atlas Powder Company with Government support, is still larger. It started operations on July 20th, 1917, after having been built in 100 days only. The plant employed 100 officials and 1,800 labourers, and during the short period during which it was working it produced 300 tons of ammonium nitrate daily, containing an average of 94 per cent. of NH_4NO_3 and 2 per cent. of moisture; it was closed at the conclusion of the truce. Ammonium nitrate was produced at Perryville by double decomposition of 300 tons of $(NH_4)_2SO_4$, from by-product plant with 350 tons of Chile nitrate. The process used was that of Freeth and Cocksedge (U.S. Patent 1,051,097 of 1913), which resembled U.S. Patent 864,513 of 1917 and German Patent 184,144 of 1905, according to which the German firm of R. Wedekind & Co. manufactured about 1,000 tons of ammonium nitrate per annum twelve years ago. This reaction is the subject of many other patents,[2] and is also employed on a manufacturing scale by Brunner Mond & Co., Ltd., in England.

[1] *Metallbörse*, 1920, p. 961.

[2] See Bertelsmann, "Ammoniumverbindungen," in Ullmann's "Encyclopædia," vol. i., pp. 401–402.

In Perryville 4·5 tons of calcined soda are used daily for neutralising the ammonium sulphate and purifying the Chile nitrate. The buildings are constructed of ferro-concrete and hollow bricks, and the floors which come into contact with ammonium nitrate from the pumps and filters are covered with tiles. The storage sheds for raw materials consist of ten-sided and eight-sided buildings with steep pyramidal roofs, with a bucket elevator ascending to the coping. The two largest sheds each hold about 1,000 car-loads of nitrate. The crude nitrate is refined on arrival in a six-stage Dorr classifier with Oliver filters. The decomposing vats are arranged in two buildings between which the vats for the mother liquor are located. Each building contains one battery of eight horizontal reaction cylinders in series, together holding 450 tons of solution. The head between the individual vessels, of which the three last proved to be superfluous, is about 0·5 m.; 225 kg. of sodium nitrate and ammonium sulphate per minute are introduced into the first cylinder by automatic weighing machines. The hot liquor is first vigorously stirred and heated by direct steam. Great difficulties were met with in connection with the packings and pumps; ferro-silicon did not prove suitable, on account of its considerable fragility; the most suitable packing materials proved to be asbestos wool impregnated with graphite and lightly coated with soap. After the reaction has occurred, the salt solutions are evaporated in vacuum pans. Anhydrous sodium sulphate separates, and is filtered on twenty continuous Oliver filters. At temperatures below 33° C. the hydrated salt separates. The rotary cylinder of the Oliver filter is covered with aluminium gauze of 6 mm. mesh, over which is placed a woollen filter-cloth, which is held in position by strong monel metal wire at intervals of 4 mm. Monel metal is supplied by the Oxford Copper Company, and contains 70 per cent. Ni, 28·9 per cent. Cu, and 1 per cent. Fe. Cotton filter-cloths are rapidly destroyed, but the woollen cloths last for one week, and cost $67 per filter. The aluminium and the monel metal last indefinitely. The separated sulphate is washed with distilled water, refiltered, and carried to the storage bins on a belt conveyor. Belt conveyors were also found excellent for the transport of the nitrate, ammonium sulphate and soda. The liquor from the Oliver filter flows into the crystallising plant, which is housed in two sheds. Each shed contains four divisions, of which each contains 15 rows of crystallising pans, 8 in each row, arranged in steps, and each holding 1·13 cu. m.; 120 of these crystallising pans are filled per hour. In each division there are four Carrier regulators, which accurately control the temperature and degree of saturation of the air. The

temperature of the crystallising boxes must be maintained at over 20° C., as at a lower temperature sodium salts would also be separated. The mother liquor passes from the boxes into storage vats. It is concentrated in three vacuum pans, each holding 25·5 cu. m., and then returns into the circuit. The ammonium nitrate crystals are washed with condenser water and passed by a belt conveyor into 32 Tolhurst centrifuges with bottom discharge. In these the water contents are reduced to 2 to 3 per cent. The finished ammonium nitrate falls out of the centrifuges on to a belt conveyor, which carries it into raised bins, from which the railway trucks are filled. Latterly ammonium nitrate has been recommended in America as a fertiliser. In view of the present high freight rate, it is very suitable as a fertiliser for the tropics, on account of its large content of nitrogen.[1]

Apart from the Du Pont Company, of New York, the General Chemical Company of New York is the most important chemical enterprise in the United States. In December, 1919, it acquired the plant of the Western Chemical Company of Denver for $2,000,000, and now owns works in the following localities: Baltimore (Maryland), Bay Point (Cal.), Bayonne (N.J.), Buffalo (N.Y.), Chicago (Ill.), Camden (N.J.), Chicago Heights (Ill.), Claymont (Del.), Cleveland (Ohio East), St. Louis (Ill.), Easton (Pa.), Edgewater (N.J.), Laurel Hill (N.Y.), Newell (Pa.), Passiac (N.J.), Pulaski (Va.), and Denver (Col.).

Under the auspices of its President, W. H. Nichols, the General Chemical Company acquired a considerable influence in the National Aniline and Chemical Company during the War; this latter company was founded with German capital.[2] In 1920 a formal amalgamation took place of the General Chemical Company, the Barrett Company, the Semet Solvay Chemical Company and the National Aniline Company. The new company is said to have a capital of $350,000,000.[3] Its yearly income must be about $30,000,000, of which about $12,000,000 may be ascribed to the National Aniline Company.

At the Laurel Hill (N.Y.) works of the General Chemical Company the first experiments were made with the modified Haber process working at lower pressures, later results with which, at the Government plant at Sheffield, Alabama, were very bad. The catalytic oxidation of ammonia is also carried out at Laurel Hill. The further progress of the experiments resulted in so many points of contact with the Semet Solvay Company's work on am-

[1] *Chem. Met. Eng.* **20**, 320–326 (1919); *Chem. Zentralbl.*, 1919, iv., 430.
[2] *Chem. Ztg.*, 1918, p. 562.
[3] *Zeitsch. f. angew. Chem.*, 1920, ii., 299.

monia oxidation at Syracuse (N.Y.) that a new company, the Atmospheric Nitrogen Corporation (of Manhattan), was founded in 1920 by the General Chemical Company and the Solvay Process Company with a capital of $5,000,000. The Atmospheric Nitrogen Corporation (of Manhattan) intended to erect a large experimental plant at Syracuse, covering 50 acres, at a cost of $1,000,000. It was, however, considered that the results obtained in the interval would enable satisfactory manufacture by the synthetic process of the General Chemical Company to be achieved; this process was due to de Jahn,[1] and is very similar to the Haber-Bosch process. It was intended that the Syracuse plant should produce 9 tons of NH_3 daily. Electric power is supplied by the Niagara, Stockport and Ontario Power Company. Up to date, however (at the end of 1921), no success has been achieved.

When discussing Parsons' report we mentioned those processes which fixed nitrogen in the form of cyanide by the action of atmospheric nitrogen on alkalies, carbon and iron at a high temperature. The Nitrogen Products Company is operating two experimental plants at Saltville, Virginia, and Niagara Falls, Ontario, which are working by the process of J. E. Bucher.[2] In the second half of 1918 the Saltville Works were extended to manufacture 10 tons of NaCN per day to be used for purposes of gas warfare. The process still presented manufacturing difficulties, and the optimistic view of Parsons (p. 275) was not fully confirmed. Bucher's process does not merely consist in the production of cyanide, but decomposes this product further with steam under pressure according to the equation:—

$$NaCN + 2H_2O = H.COONa + NH_3.$$

The Air Reduction Company, of Jersey City, N.J., also produced a similar process for fixation of nitrogen, according to which cyanide, ammonia, ammonium salts, formates, formic acid and esters are actually produced on a manufacturing scale. A portion of the formate is converted into oxalate or oxalic acid, according to the equation:—

$$2NaOOCH = Na_2C_2O_4 + H_2,$$

hydrogen being obtained as a by-product. In a special report of the U.S. Tariff Commission[3] the following statement is made: "The development of this whole branch of industry was hindered during the War by the fact that it was classified by the War Department as inessential, and could not therefore obtain raw materials and labour; the United States should, however, establish a formic and oxalic acid industry, independent of foreign sources, by imposing suitable

[1] *Chem. Ztg.* 1920, pp. 596, 720.
[2] *J. Ind. Eng. Chem.*, 1917, p. 233; *Eng. Min. Journ.*, 1917, p. 53.
[3] *Chem. Ztg.*, 1920, p. 583.

import duties, more particularly on sodium formate." The duty on this product is at present 1½ cents per pound. From July 1st, 1913, to June 30th, 1914, the United States imported 508 tons of formic acid, of which 85·7 per cent. came from Germany; in the three succeeding years the imports diminished considerably, being 242·68 tons in 1914-15; 59·88 tons in 1915-16, and 174·64 tons in 1916-17. During this period the average value has increased almost six-fold. 836 tons of technical sodium formate were imported in 1913-14, almost exclusively from Germany.

According to various Press articles,[1] the following companies are also active in connection with nitrogen fixation: The Standard Electric Power and Chemical Company of Vancouver, Washington, on the Deschutes River; the International Nitro-Fix Company of Wilmington, Del.; the Arnold-Hoffmann Company of Providence (Rhode Island), and the Mathieson Alkali Company at Niagara Falls. The two latter firms intend to produce synthetic ammonia. Their processes have been produced by Edward E. Arnold and by M. J. Chaley respectively, the latter being the head chemist of the Mathieson Company. A plant is being built at Niagara Falls which is to manufacture 10 tons of NH_3 daily.

The rapid development of the Atmospheric Nitrogen Industry is exceeded by the large increase in the development of by-product coke ovens.[2] The coal production of the United States was as follows:—

Year.	Hard coal. Short tons.	Soft coal. Short tons.
1916	88,000,000	503,000,000
1917	100,000,000	552,000,000
1918	99,000,000	579,000,000
1919	88,000,000	458,000,000
1920	89,000,000	557,000,000

In 1892 the first by-product plant was operated by the Solvay Company, in order to produce the ammonia necessary for the ammonia soda process. The development of ammonium sulphate manufacture is shown in the following table:—

Year.	Ammonium Sulphate Production in tons.
1900	58,000
1910	116,000
1911	115,000
1912	149,700
1913	176,900
1914	166,014
1915	220,000
1919	303,100

[1] *Chem. Ztg.*, 1917, p. 480; 1918, p. 531; 1919, p. 806; 1920, pp. 8, 583.
[2] *Metallbörse*, 1921, p. 401.

The indirect stimulus to this extraordinary development was due to England, which allowed the competition of the United States during the War to become as strong as possible on the world's market and so encouraged a serious competitor. England paid extraordinarily high prices to the United States for all its products, and thus placed the American industry in a position completely to write off their newly constructed plants within one to two years. It is now believed that the American producers will not be able permanantly to dispose of the enormous quantities of benzene and toluene produced.

During the War, however, the favourable economic circumstances enabled them to dispose of these by-products on the world market at extraordinarily cheap prices, as most of the plants, as already mentioned, are valued at a very low figure, and thus the manufacturing costs of coke, gas and ammonium sulphate are reduced very greatly. The favourable position of the American coking industry is shown by a comparison between the production of by-product ammonia in the principal countries in the years 1913–14 and 1919.

	England.	United States.	Germany.
	Tons.	Tons.	Tons.
1913–14 (approx.)	425,000	175,000	500,000
1918	262,140	468,525	500,000
1919 (approx.)	380,000	300,000	250,000
Difference between 1913–14 and 1919.	− 45,000 = − 10·6 per cent.	+ 125,000 = + 71·5 per cent.	− 250,000 = − 50 per cent.

In America this production was distributed as follows :—

	1913	1914	1915	1916
	Tons.	Tons.	Tons.	Tons.
From coke ovens	138,799	126,552	159,655	264,754
From gas works, gas producers, and so forth	38,102	29,463	39,916	48,081
	176,901	156,015	199,571	312,835

Not more than 7,000 tons of synthetic ammonium sulphate, from calcium cyanamide and so forth, were produced in the United States in 1916; in later years this amount diminished still further, as the synthetic ammonia was mainly oxidised to nitric acid. A picture of the development of the American coking industry is given

by the following table,[1] which gives the coke production in tons from by-product and bee-hive ovens:—

Year.	Coke production in by-product ovens.		Coke production in bee-hive ovens.		Total Production.
Per cent.	1,000 tons.	Per cent.	1,000 tons.	Per cent.	1,000 tons.
1880	—	—	3,338·3	100·0	3,338·3
1885	—	—	5,106·7	100·0	5,106·7
1890	—	—	11,508·0	100·0	11,508·0
1893	12·9	0·1	9,464·7	99·9	9,477·6
1900	1,075·7	5·2	19,457·6	94·8	20,533·3
1905	3,462·3	10·7	28,768·8	89·3	32,231·1
1910	7,138·7	17·1	34,570·1	82·9	41,708·8
1913	12,714·7	27·5	33,584·8	72·5	46,299·5
1914	11,219·9	32·5	23,336·0	67·5	34,555·9
1915	14,072·9	33·8	27,508·3	66·2	41,581·2
1916	19,069·0	35·0	35,464·0	65·0	54,533·0
1917	22,439·0	40·3	33,167·0	59·7	55,606·6
1918	25,998·0	46·0	30,480·0	54·0	56,478·0
1919	25,171·0	56·0	19,650·0	44·0	44,821·0

In 1916 44 by-product plants treated 29,000,000 tons of coal; 18 further plants were being erected for the treatment of 15,000,000 tons of coal annually. In 1917 the total production of coke was 55,610,000 tons from 83,750,000 tons of coal. In 1916 nearly 20,000,000 tons of coke were produced in by-product ovens compared with less than 5,000,000 tons in 1906. About 60 per cent. of the coke oven gas is available for other purposes.[2] The number of plants producing benzole was 30 in 1915; 39 in 1916; and 47 in 1917.[3] In 1917 there were 7,298 by-product coke ovens compared with 6,036 in 1915 and 8,137 in 1918. The production of coke in by-product ovens was 59 per cent. greater in 1917 than in 1915. The yield of coke from such ovens varied in 1915 from 60 to 77 per cent., the average being 71·2 per cent., whilst in beehive ovens the production in 1918 was 59,661 tons, and the yield of coke 60 to 75 per cent., with an average of 63·5 per cent., all the by-products being, of course, lost. In by-product ovens the yield of coke essentially depends on the composition of the charge, whilst in beehive ovens it varies with the manner of coking. The same coal yields about 11 per cent. more coke in a by-product oven than in a

[1] Pamphlet of the firm of Koppers, 1919, No. 9; *Chem. Ztg.*, 1920, pp. 31, 631, etc.
[2] *Journ. f. Gasbel.*, 1917, p. 479.
[3] *Chem. Ztg.*, 1920, p. 31.

beehive oven.[1] In 1918 the production of the beehive ovens was 8 per cent. less than in 1917, whilst that of the by-product ovens increased by 17 per cent.[2] The decrease in the production which occurred in 1919, on account of a reduction in the demand, characteristically affected the beehive ovens almost exclusively; it amounted to 36 per cent.[3] 1919 was the first year in which the production of the by-product ovens exceeded that of the beehive ovens. In 1919 1,228 new by-product ovens were completed in the United States, so that the total number of these at the end of 1919 was about 11,200. Out of the additional 1,228 ovens, 718 were in new plants, and 510 in extensions. On January 1st, 1920, 850 by-product ovens were under construction.[4] The annual production of the by-product ovens at full capacity was 33·7 million tons of coke in 1919 and 39·5 million tons of coke in 1920. The official estimate of the maximum production capacity of by-products for 1919 was as follows :—

303,100 tons of ammonium sulphate, ammonia and so forth.
951,290 cu. m. of tar.
321,392 cu. m. of crude tar oil.
10,413,000,000 cu. m. of gas.

The production of pure benzene was 79·6 million litres in 1916 and 140·2 million litres in 1917. In 1917 about 28,000,000 litres of toluene were produced. The total value of by-products was 137·3 million dollars in 1916 and more than 206·3 million dollars in 1917. In 1919 the total production of the beehive ovens was 19,650 tons, and in 1920 20,833 tons.[5]

Among the various systems of by-product ovens used in the United States the German Koppers oven is the most usual ; in August, 1919, there were no fewer than 6,416 such ovens in the United States actually working or under construction. At the commencement of 1915 the H. Koppers Company transferred their head offices from Chicago to Pittsburg, where they established a large central organisation. At the commencement of 1918 there were 9,282 by-product ovens at work. Between 1908 and 1918 5,483 new ovens were erected, of which 4,996, or 91 per cent., were Koppers ovens ; 72 per cent. of the by-product ovens in the country are therefore Koppers ovens. In 1920 the Koppers Company brought a new type of oven on to the market.[6] An idea may be

1 *Chem. Ztg.*, 1920, p. 631.
2 *Zeitsch. f. angew. Chem.*, 1919, ii., 287.
3 *Chem. Ztg.*, 1920, p. 546.
4 *Metallbörse*, 1920, p. 879.
5 *Ibid.*, 1921, p. 401.
6 *Chem. Ztg.*, 1920, p. 631.

obtained of the splendid development of American by-product works from the description of the plant of the Seaboard By-Product Company, of New Jersey, with 165 ovens, and of the Carnegie Steel Company, of Clairton, with 768 ovens and a daily production of 147 tons of ammonium sulphate; descriptions of these, gathered from American sources, will be found in Koppers' Pamphlet No. 9, of 1919.[1]

The new plant of the Providence Gas Company No. 3, contains forty regenerative Koppers ovens.[2] The Illinois Steel Company of Gary (Ind.) owns 700 coke ovens.[3] The new plant of the Sloss-Sheffield Steel and Iron Company at Birmingham (Ala.) treats 2,500 tons of coal daily, producing approximately 30 tons of ammonium sulphate.

An essential difference between American and German coke-oven plants consists in the fact that in America these are all situated near the iron works, whilst in Germany they are at the colliery.[4] In America the manager of the blast furnaces has the control of the coke ovens, and takes care that he obtains the coke which he requires. The coal first undergoes a careful preparatory treatment; after being washed, the water content is reduced to 8 to 9 per cent., and the coal is finely ground, and if necessary, blended. The following table will show that the technical and commercial developments of the coke-oven industry have gone hand in hand:—

	End of 1914.			End of 1918.		
	Germany.	United States.	England	Germany.	United States.	England.
Amount of coal treated annually in by-product ovens in million tons . . .	35	26·5	15	41	50	21
Number of by-product coke ovens	20,173	6,438	7,813	22,003	9,940	9,827
Annual amount of coal treated per oven (in tons) . .	1,750	4,100	1,900	1,800	5,030	2,130

The advantage of America in cheapness of coke production, due to the extensive application of mechanical appliances in the works and the increased output per oven, is very considerable. Modern American developments afford valuable guidance for the improvement of German and English methods of coking, which is much to be desired. The construction of small coke-oven plants should be

[1] See also *Zeitsch. f. angew. Chem.*, 1918, ii., 470.
[2] *Chem. Zentralbl.*, 1919, iv., 1069.
[3] *Zeitsch. f. angew. Chem.*, 1918, iii., 482.
[4] *Ibid.*, 1917, ii., 774.

avoided here, and endeavours should be made to erect large installations only and, so far as possible, to combine former smaller installations. High profits in the coke-oven industry can only be obtained in large installations, in the construction of which false economy should not be allowed to play any part.

The People Gas Company of Chicago, the largest gas works in the world, have so far enriched their water-gas with oil-gas. In 1918 they were about to construct coke ovens for an annual production of 500,000 tons of coke and the accompanying by-products. Long-distance transmission mains for coke-oven gas exist, for example, between the Clairton coke ovens and a steel works at Pittsburg. This is 17·7 km. in length ; the gas transmission main to the town of Barmen, Germany, is 47 km. in length.

Chas. H. Smith has produced an interesting process for the low-temperature carbonisation of coal, which has also been applied in England. Coal is first heated in retorts with mechanical stirrers at 425° C. to 475° C. for one to two hours, thus obtaining a large yield of gas and tar. The carbon residue, "semi-carbocoal," is mixed with pitch obtained from the tar and converted into briquettes, which are heated in retorts to about 980° C. for four to five hours, so producing the final product, "carbocoal." From 1 ton of crude coal there are obtained 9·5 kg. of ammonium sulphate, 169 cu. m. of gas in the first distillation, and 113 cu. m. of gas in the second distillation, as well as 110 litres of liquid constituents—namely, light, middle and heavy oils, creosote oils and pitch. The Pennsylvania Railway Company has obtained excellent steam-raising results when burning carbocoal under their boilers. Carbocoal crumbles with difficulty, and stands transport very well. After the favourable results of trials carried out by the Navy Department, an agreement was made in 1919 with the Fuel Administration and the Ordnance Bureau for the erection of a carbocoal plant in the United States for the treatment of about 1,500,000 tons of coal annually.[1] The English Carboyl Syndicate, Ltd., which was founded in 1913, has evolved a process which yields no coke, but is said to convert the coal completely into ammonium sulphate and oil.[2] The raw material for this process is not high-grade coal, but coal-waste of all sorts. For the purpose of granting a licence and erecting a plant, the Carboyl Syndicate, Ltd., has meanwhile allied itself with the American Vulcan Trading Corporation, and is issuing new shares to the value of £300,000. The American Coal Refining Company proposes to convert non-coking coal from north-east Colorado into

[1] *Chem. Ztg.*, 1920, p. 25; 1919, pp. 7, 36 *Zeitsch. f. angew. Chem.*, 1918, iii., 490.
[2] *Ibid.*, 1920, ii., 164.

a smokeless fuel, resembling anthracite, and into gas, tar and ammonia.

But little has so far been effected in America towards the exploitation of the very considerable peat deposits, which are estimated to contain 14,000,000,000 tons and cover an area of 40,000 sq. km. Only 47,380 tons of peat were utilised in 1912 and 151,521 tons in 1918, of which 20,567 tons were used for heating. It is only quite latterly that this matter has received further attention. In *Chemical and Metallurgical Engineering*, No. 20, pp. 693–696 (April 14th, 1920), H. Philipp gives detailed data regarding peat production since 1908, with analyses, and on the development of the American peat industry in general. The Governments of Maine and Massachusetts have devoted special attention to the investigation and development of peat deposits. The U.S. Geological Survey issued instructions on the utilisation of peat in gas producers and for other purposes in the form of a pamphlet.

Black peat is increasingly used as a fertiliser. It contains more nitrogen and less fibre than the brown variety. The reserves of peat in Minnesota are estimated at 1,330,000,000 tons. Special laws have been enforced in that state regarding the exploitation of the peat deposits. Attention is being mainly directed to the manufacture of peat charcoal.

The natural gas fields are also utilised for supplying the chemical industry with fuel ; thus, for example, the Anaconda Copper Mining Company established itself near the gas wells at Sweet Grass.[1] In Colorado and Utah the exploitation of oil shales, which are richer than the Scottish shales, has been commenced.[2]

Kelp is treated for the production of ammonia and ammonium salts, in addition to potash salts, iodine, acetone and so forth. It has been shown at the Government experimental station at Summerland (California), that the nitrogen in kelp is almost entirely recovered in the form of ammonia. The works of the Hercules Powder Company at Potash, near San Diego (California), which cost \$6,000,000, were closed temporarily at the conclusion of the truce.

The firms prominent in the liquefied gas industry are : the Linde Air Products Company of New York, which operates the Linde process, and the Air Reduction Company, New York, which utilises the Claude process. The latter company amalgamated in 1917 with the National Carbide Company and the Union Carbide Company, in order to find an outlet for nitrogen. In 1918 an agreement was signed between the National Carbon Company, the Union

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 29.

[2] *Chem. Ztg.*, 1917, p. 179 ; *Zeitsch. f. angew. Chem.*, 1918, iii., pp. 263, 526, 550.

Carbide Company, the Presto-O-Lite Company, and the Linde Air Products Company for the erection of a works at Youngstown, Ohio, for the production of carbide and other gas-generating material.

The Linde Air Products Company and the Air Reduction Company are both interested in the development of the American helium industry. The natural gas from a well at Petrolia, Texas, contains 0·4 to 1·0 per cent. of helium. The gas serves for supplying the town of Fort Worth, 160 km. distant, with 560,000 cu. m. daily. In November, 1917, the erection of two plants at Fort Worth was commenced for the production of helium from this natural gas. The Linde Company was commissioned to isolate about 141·5 cu. m. of 90 per cent. helium daily, whilst the Air Reduction Company was to produce 85 cu. m. daily. Both plants started production in March, 1918. The Linde plant concentrated the 72 per cent. crude gas to 92 to 93 per cent. The plants worked experimentally for about two months and were then closed. Plant 1, the Linde plant, was immediately dismantled, whilst Plant 2 of the Air Reduction Company continued to work for a short time in an endeavour to improve the process. At the conclusion of the truce about 5,660 cu. m. of helium gas had been produced, of which about 4,150 cub. m. was stored in cylinders ready for transport. Meanwhile the Naval Department, under the direction of R. D. Moore (June, 1918, to June, 1919), had carried out their own experiments at Petrolia, which established the suitability of a third process which was due to F. E. Norton, and was carefully tested by the National Research Council. Norton utilises triple expansion engines.

The gas stream is throttled and heat transference and fractionation are carried out by new methods. The power requirements for compressing the gas are reduced to a minimum. The processes of Claude and Jefferies-Norton differ from that of Linde by the fact that the compressed gas is made to produce work in one or more expansion engines before liquefaction in Claude's system and after liquefaction in that of Jefferies-Norton, whereas in Linde's process this is not the case, and the gas is allowed to expand freely through an expansion valve. In Linde's method the use of complicated movable parts, which are readily frozen up, is avoided, but, on the other hand, it requires higher initial pressures, of 100 to 200 atmospheres, and perhaps utilises the heat less satisfactorily than the other systems. Details of the methods of rectification of liquefied natural gas have not yet been published.[1] The application of the Jefferies-Norton process on the large scale met with so many difficulties that the Petrolia plant only started operation in March,

[1] *Umschau*, 1919, p. 487.

1919. The concentration of the helium which was produced was in the first instance only 21 per cent. The Navy Office produced plans in 1919 for a large new plant at Fort Worth at a cost of $2,000,000, and with an output capacity of 850 cu. m. daily.[1] During the War the gas was known as "argon," in order to baffle spies. Argon itself is produced as a by-product by the American Cyanamide Company and others. Helium is of importance for use in airships on account of its non-inflammability, in consideration of which its relatively high specific gravity, which is 0·1708 gm. per litre, compared with 0·0899 gm. per litre for hydrogen, is relatively unimportant. It is said that the production costs of helium have been reduced from $60,000 to $3·50 per cu. m. The Committee of Congress which was formed to study the industrial production of helium, in which the United States has invested $6,000,000, reported very unfavourably early in 1920, in spite of the above results. According to the Committee's report, the production cost of the helium for filling an airship would be larger than the cost of the airship itself. The Committee therefore advised that no more money should be spent until cheaper methods of manufacture had been discovered.[2] A Bill has been introduced to prevent the export of helium under heavy penalties, as the available sources of this gas are restricted.

The following quantities of fertilisers were used in the United States in 1914:—

	Tons.
Materials containing ammonia	1,463,278
Cotton-seed meal	325,234
Slaughter-house offal and other nitrogenous materials	887,934
Fish offal, etc.	250,110
Ammonium sulphate	149,924
Calcium cyanamide	25,911
Nitrate	147,150

It should be noted that a large portion of the cotton-seed meal, offal, and fish-meal are used as feeding stuffs.

At the end of December, 1915, the Government estimated the consumption of nitrogenous fertilisers to be as follows:—

	Tons.
Nitrates	70,000
Ammonium sulphate	215,000
Cotton-seed meal	1,000,000
Blood meal	40,000
Slaughter-house offal	10,000
Fish offal	70,000

[1] *Zeitsch. f. angew. Chem.*, 1019, ii., 736.
[2] *Ibid.*, 1920, ii., 138.

The exceptionally interesting paper of Alfred H. White [1] gives the following figures :—

I. Supplies of Fixed Nitrogen to the United States in 1913.

(*a*) Stocks, imports and production :—

	Tons.		Tons of Nitrogen.
Chile nitrate	636,047	=	98,884
Imported ammonium salts, calculated as sulphate	59,670	=	12,292
Production of ammonium sulphate from coke ovens and gas works	176,900	=	36,469
Calcium cyanamide from the American Cyanamide Company	15,000	=	3,000
			150,645

(*b*) Consumption :—

Imported Chile nitrate :—

	Tons.		Tons of Nitrogen
For fertilisers	249,339		
For explosives	289,371		
For chemical industry, etc.	97,337		
	636,047	=	98,884
Ammonia and so forth :—			
Ammonium sulphate for fertilisers	117,935	=	24,312
Calcium cyanamide	15,000	=	3,000
Ammonia for industrial purposes			27,216
			153,412

II. Supplies of Fixed Nitrogen to the United States in 1920.

	Tons of Nitrogen.
Prospective requirements	210,468
Production from coke ovens, gas works and the American Cyanamide Company	84,097
Difference	126,371
Possible production of the U.S. Nitrate Plant No. 2 at Muscle Shoals	37,647
Deficit to be supplied by imports	88,723

Thus 42·1 per cent. of the total requirements, or 546,150 tons of Chile nitrate, must be imported. Excluding Muscle Shoals, 60·4 per cent. of the requirements, or 721,400 tons of Chile nitrate, remain to be imported.

In 1925 and 1930 the requirements will presumably be still less adequately covered, if the consumption increases normally and no new producers of synthetic nitrogen compounds appear. This is on the assumption that the U.S. Nitrate Plant No. 1 at Sheffield

[1] *Chem. Met. Eng.*, 1920, pp. 369–371.

produces 7,710 tons of nitrogen per annum. Assuming total requirements of 415,675 tons of nitrogen (in 1913), and a production of 117,935 tons of nitrogen from coke ovens, gas works, private cyanamide plants and so forth, together with a production of 37,648 + 7,710 tons of nitrogen from the Government plants, it would be necessary to import 1,625,000 tons of Chile nitrate in order to cover the deficit. On the assumption that White's figures are valid for the future, the dependence of the United States on Chile is so considerable that, if only for this reason, it is desirable to assist the domestic nitrogen industry by all possible means.

The Geological Survey refers to the first domestic production of sodium cyanide, other cyanides and sodium nitrate in 1917. This amounted in short tons to the following figures :—

	1917	1918.	1919.
Sodium cyanide and so forth	10,548	9,077	9,196
Sodium nitrate, refined .	781	—	6,512
Sodium nitrite . . .	—	1,701	431

The imports of cyanide in 1916–17 were unimportant. The very large imports of Chile nitrate have already been discussed in connection with that industry.

The sulphuric acid industry of the United States has grown considerably ; its production increased from 2,710,000 short tons in 1913 to 4,950,000 tons in 1919, calculated as 100 per cent. acid. At the commencement of 1918 the output capacity was 5,124,000 short tons of acid of 50° Bé., whilst in November it was 9,000,000 tons ; of this quantity 1,040,000 tons could be produced by the Government works, 1,120,000 tons by the explosives companies' works, and the remaining 7,440,000 tons by others. About 2,500,000 tons are required for the production of fertilisers.

The actual output capacity of the more important nitrogen works is at present approximately as follows :—

Coke ovens, etc. :		
300,000 tons of ammonium sulphate .	approx.	61,500 tons N.
American Cyanamide Company :		
64,000 tons of cyanamide . .	,,	12,800 tons N.
U.S. Nitrate Plant No. 1 (Synthetic process) :		
Various nitrogen products . . =	,,	7,710 tons N (= 37,625 tons of ammonium sulphate).
U.S. Nitrogen Plant No. 2 (Cyanamide process) :		
Various nitrogen products . . =	,,	37,650 tons N (= 183,730 tons of ammonium sulphate).
Arc process :		
10,000 tons of HNO_3 . . . =	,,	2,220 tons N.
Cyanide process and cyanide from other sources :		
10,000 tons of sodium cyanide . =	,,	2,850 tons N.
Total . . .	,,	124,730 tons N.

In the spring of 1919 the output capacity of plants for the production of nitric acid from Chile nitrate and sulphuric acid was about 650,000 tons of nitric acid, and that of the ammonia oxidation plants 225,000 tons, calculated as 100 per cent. acid. As the imports of Chile nitrate in 1918 were approximately 1·6 million tons, equal to approximately 249,600 tons of nitrogen, it follows that the total production of fixed nitrogen in the United States in 1918–19 was approximately :—

$$127{,}580 + 249{,}600 = 377{,}180 \text{ tons of nitrogen.}$$

W. S. Landis, of the American Cyanamide Company, estimates the maximum resources of the country, including the quantities imported in the forms of cyanide, ammonia, ammonium salts, potassium nitrate, cyanamide, etc., and allowing for the quantities present in organic fertilisers at about 460,000 tons of nitrogen.[1] The imports in tons in 1918 and 1919 were :—

	1918.		1919.
Potassium cyanide	64·4	..	553·4
Potassium nitrate (crude)	4,239·0	..	17,079·0
Sodium cyanide	31·3	..	2,347·0
Chile nitrate	1,673,784·0	..	369,230·0
Ammonium chloride	129·3	..	514·0
Ammonium sulphate	2,714·2	..	2,149·2
Calcium acetate, chloride, carbide and nitrate	21,269·3[2]	..	30,089·5
Calcium cyanamide	237,686·0[2]	..	563,371·0

The exports in tons included :—

	1918.		1919.
Nitric acid	459·5	..	227·7
Calcium carbide	8,231·0	..	10,842·4

The extraordinary dimensions of American foreign trade will be clear from the following figures,[3] which refer to periods from July 1st to June 30th :—

	Value of Imports.	Value of Exports.	Excess of Export Values.
	$	$	$
1917–18	2,945,655,403	5,919,711,371	2,974,055,968
1918–19	3,095,876,582	7,224,744,785	4,128,871,681
1919–20	5,239,000,000	8,111,000,000	2,872,000.000

[1] *Zeitsch. f. angew. Chem.*, 1919, ii., 794.
[2] From July 1st.
[3] *Zeitsch. f. angew. Chem.*, 1920, ii., 309.

At the commencement of 1920 there were rumours in the United States of an official price limit for ammoniacal fertilisers which led to a notice by the Bureau of Agriculture[1] to the effect that unrestricted prices for ammonium sulphate and so forth were entirely desirable. During 1920 the most important products were sold at the following prices :—

Ammoniacal liquor, concentrated	1 lb.	8¾ to 10¾ cents.
Anhydrous ammonia	,,	33 ,, 38 ,,
Ammonium chloride, granulated, white	,,	16 ,, 18 ,,
Ammonium carbonate	,,	16 ,, 16½ ,,
Ammonium nitrate	,,	10 ,, 11 ,,
Ammonium sulphate (average)	100 lb.	$5·50
Calcium carbide	1 lb.	4½ to 5½ cents.
Potassium nitrate, granulated)	,,	13¼ ,, 14½ ,,
Sodium cyanide (technical)	,,	28 ,, 30 ,,
Chile nitrate	100 lb.	$3·85
Sodium nitrite, 96 to 98 per cent.	1 lb.	15 ,, 15½ ,,
Nitric acid, 42° Bé.	1 cwt.	$8·00 to $8·50
Nitric acid, 36° Bé., in carboys	,,	$6·50 ,, $7·00

Supplement. 1921–4.

The general tendency of development is to increase imports from Chile and thus to establish a reserve, whilst the existing plants for the fixation of atmospheric nitrogen are to be continued as a sort of war insurance, meanwhile developing the coke-oven industry. The production of ammonium sulphate in short tons was :—

1914	186,749	1919	545,116
1916	235,265	1920	469,693
1918	378,000	1922	449,233

In 1922 the coke ovens produced 28,319,000 tons of coke in by-product ovens and 8,007,000 tons in beehive ovens. There were also produced 365,000,000 gallons of tar, 111,000,000 gallons of crude light oil, and 898,465 tons of ammonia in all forms, calculated as ammonium sulphate. The output of coal was 517·2 million tons in 1913 and 417·84 million tons in 1922 (*Chem. Ztg.*, **1923,** 75 ; *Chem. Ind.*, **1923,** 142. 182, 188, 285, 482, 556, 620, 645, 655 ; *Metallbörse*. **1923,** 300, 1904, 2024 ; **1924,** 211).

The final disposal of the works at Muscle Shoals. the largest cyanamide works in the world, which only maintained production for a short time after the truce, has not yet been definitely decided. The Ford interests are known to be endeavouring to obtain control.

Nitrate factory No. 1 at Sheffield (Ala.). which was to have operated the Haber process, was a complete failure.

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 71.

Meanwhile, the Atmospheric Nitrate Corporation has erected a small works which operates the de Jahn process, of which 10 units were ready in 1920–21. The beginnings of an arc nitric acid industry are appearing in the Western States.

The experimental plant at Saltville which was working Bucher's cyanamide process was closed at the end of the War. On the other hand, a new works for the production of prussic acid and cyanide was being erected in California by the Air Reduction Company in 1923. Prussic acid is to be used as an agricultural insecticide.

The American Cyanamide Company convert a large part of the cyanamide which they obtain into urea, ammophos (*i.e.*, ammonium phosphate fertiliser) and cyanide.

A Casale plant is being erected at Niagara Falls.

At Fort Worth there are six Linde plants which produce 850 cu. m. of 90 to 95 per cent. helium daily at a very cheap rate.

The annual loss of helium in the United States is 500,000,000 cu. ft.

Technical research is organised on very large lines (*Chem. Ind.*, **1923,** 347, 523).

In the fiscal year 1921–22, 168,127 tons of ammonium sulphate were exported, and 144,646 tons in 1922–23. The imports of Chile nitrate were: 1,237,500 tons in 1920; 372,500 tons in 1921; 542,464 tons in 1922; and 639,692 tons in the first half year of 1923.

The imports of cyanamide, which came from Canada, were 41,807 tons in 1922. The production in 1918 was 945,000 tons of nitric acid, 457,000 lb. of potassium ferrocyanide, and 4,525 tons of ferrocyanide. The value of the total production of nitrogen and its products was $33,088,000 in 1921 (*Chem. Ztg.*, **1922,** 691, 870, 894; *Chem. Ind.*, **1923,** 141, 180, 238, 285, 390, 426, 449, 540, 620, 645, 655; **1924,** 20; *Metallbörse*, **1923,** 1272).

CHAPTER XII

The Canadian Nitrogen Industry

CANADA is very rich in water power. There is at least 14,000,000 h.p. which is relatively easy to exploit, and about 19,000,000 h.p. altogether. Of this quantity about 5,800,000 h.p. is in Ontario, 6,000,000 h.p. in Quebec, and 3,000,000 h.p. in British Columbia. In 1918, 1,800,000 h.p. was being exploited, and 2,300,000 h.p. in 1920, whilst 1,000,000 h.p. was in course of development.

The peat moors of the United States are estimated to cover 40,000 sq. km., while those of Canada which have already been investigated amount to 37,000 sq. km., and are in many cases distinguished by the exceptional thickness of the peat layer. According to investigations of the Canadian Government, in the immediate neighbourhood of Ottawa [1] alone there are four peat deposits which together contain about 25,000,000 tons of fuel. These moors were scarcely utilised before the War, although a rational reclamation of these areas and exploitation of the enormous quantities of fuel which they contain would render Canada independent of coal imports from the United States. In 1920 a Government plant at Alfred was producing 30 tons of peat fuel daily, and a company had been formed for the exploitation of the moors, the Canadian Peat Society.

The coal production of Canada was 5,088,000 tons in 1900, and 14,706,000 tons in 1913. Interesting statistics were obtained by a Canadian Government commission, which reported on the advantages of central power stations as compared with a multitude of small stations; the coal consumption in tons per horse-power year at power stations was as follows:—

	Tons.
Under 1,000 kw.	25·00
From 1,000 to 5,000 kw.	14·00
,, 5,000 ,, 10,000 ,,	13·30
,, 10,000 ,, 50,000 ,,	9·32
,, 50,000 ,, 100,000 ,,	6·57

The works of the American Cyanamide Company, the Canadian Aloxite Company, the Acheson Graphite Company and others, are established on the Canadian side of the Niagara Falls. The oldest

[1] *Chem. Ind.*, 1912, p. 294.

electro-chemical industry is the manufacture of aluminium. For this purpose the former Pittsburg Reduction Company, now the Northern Aluminium Company, utilises 50,000 to 60,000 h.p., mainly at Shawinigan. Calcium carbide is produced by the Willson Carbide Company at St. Catherines, Ontario, the Shawinigan Carbide Company at Shawinigan Falls, and the Union Carbide Company of Canada, Ltd., at Welland, Ontario. The Canadian Electrode Company produces large carbon electrodes, and has a normal output of about 15 tons daily. The Shawinigan Electro-Metals Company produces, among other products, metallic magnesium of 99·5 per cent. purity; it employs 2,500 h.p. The Presto-O-Lite Company compresses acetylene gas, which it buys from the Canada Carbide Company. The Canada Cement Company at Montreal has recently interested itself in the recovery of potash from flue gases; 130,000 h.p. from Niagara Falls have been utilised for the further development of the mining industry in New Ontario.

A company was formed in 1915 at St. John's, Newfoundland, for the production of timber, cellulose, calcium carbide, ammonium phosphate, ammonia and cement at Bay of Islands. Its capital is $21,000,000. The Quebec Development Co., Ltd., following the example of the Southern Electro-Chemical Co., Ltd., of New York, decided in 1916 to establish a nitric acid works near the St. John Lake on the Saguenay River.

The rapid development of the manufacture of industrial gases for welding, such as oxygen, acetylene and hydrogen, led to considerable decentralisation of the works in the United States. The large producers maintain a number of small works all over the country in order to be able to deliver under favourable transport conditions in all localities. In the compressed gas industry, where the steel bottle is several times as heavy as the contents, a reduction in the freight charges is one of the first foundations for successful development. Similar developments are now occurring in Canada, where the newly founded National Electro-Products Company intends to establish an oxygen works at Toronto, and five further works in the United States. The Dominion Oxygen Co., Ltd., also intends to erect five large works for the manufacture of oxygen, argon and nitrogen in the main industrial centres of the country. It is affiliated to the Union Carbide and Carbon Corporation, which controls 36 different companies in the United States and Canada.[1]

During the War, Chemical Products Ltd., of Canada, which had a capital in 1920 of $3,000,000, developed from small beginnings to considerable importance. In 1920 the company acquired the plant

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 211; *Metallbörse*, 1920, p. 840.

of British Chemicals, Ltd., at Trenton, Ontario, which had been erected at a cost of $3,500,000 for the manufacture of explosives for the Imperial Ministry of Munitions. In future, Chemical Products, Ltd., will devote itself not only to its previous manufacture of pharmaceutical products, such as aspirin, but also to the manufacture of other chemical products, such as sulphuric acid, nitric acid, superphosphate, refined sodium nitrate, ammonia, coke-oven by-products, and so forth.

At the end of 1919 the statistical department of the Canadian Government issued a guide to the Canadian industry which contains detailed information up to the year 1919. In this guide 634 firms are alphabetically arranged, both according to their names and their products. It also contains a complete review of the various branches of chemical industry and of their history during the last six years.

Under the direction of H. W. Matheson, the Canadian Electro-Products Co., Ltd., at Shawinigan Falls, has developed a process for the manufacture of acetic acid, acetone, and so forth, from acetylene. Early in the War there was a very large demand for acetone, which was far greater than the supply. At the request of the British War Office, the Canadian Electro-Products Company, which obtained their power from the Shawinigan Water and Power Company, investigated the question of the production of acetone from calcium carbide. They commenced to erect a plant for the purpose in May, 1916, and in November to December of the same year were already able to produce acetone. The works now contain twelve buildings. They cost $2,000,000, and are considered to be the largest plant of the kind in the world. For a whole year the acetylene was exclusively converted into acetone. The demand for acetic acid then grew to such an extent that the manufacture of acetone was entirely discontinued. The acetic acid was exclusively delivered to the Imperial Munitions Board. As the United States also showed great interest in the new process, the Washington Government approached the Shawinigan Works. These were then considerably extended. Deliveries to the United States commenced in October, 1918. The present output of the plant is said to be larger than that of all the plants of the rest of the world by the old process, that is, from grey acetate of lime.[1]

It was decided to utilise the natural gas wells of Canada for the manufacture of helium, as in the United States. It has been known since 1903 that many of the Canadian gas wells contain helium. In the spring of 1916 rather more than 0·36 per cent. of helium was

[1] See *Zeitsch. f. angew. Chem.*, 1918, iii., 617.

found in the most prolific Canadian gas well, that of Bow Island in Alberta. It has been calculated that in the natural gas used for heating in Calgary $50,000,000 worth of helium are wasted daily, at the pre-war value. The manufacture of this gas has not yet been started in Canada.

The utilisation of the gas wells of the Fraser Valley in British Columbia, which evolve almost pure nitrogen, or of those of the islands in the Gulf of Georgia, remains a problem for the future. As water power is available at Stave Lake, and limestone and coal are also found in the neighbourhood, the formation of a cyanamide and cyanide industry in that neighbourhood has been considered. The nitrate imports in 1912-13 were 36,406 tons, and in 1913–14, 12,047 tons.

With regard to exports of carbide, Canada found it very difficult to compete with Norway on the British market before the War. During the War comparatively large amounts of carbide were shipped from Canada to England. The imports were 1,772 tons in 1915, 3,707 tons in 1916, and 2,644 tons in 1917. In normal times the imports of carbide into Great Britain before the War were 26,000 tons annually, of which 18,000 tons were from Norway. It is uncertain whether Canada will be in a position to continue these imports into Great Britain permanently. The extraordinarily high freight rates are not favourable to the Canadian prospects.

In 1918 there were fifteen works with a total capital of $3,064,000, producing 75,671 tons of fertilisers of the value of $2,161,000. These fertilisers comprised 10,934 tons of nitrogenous fertilisers of the value of $481,947.

Supplement, 1921–1924

The producing centre of the American Cyanamide Company, a company domiciled in the United States, lies on the Canadian side of the Niagara Falls. In Canada there are relatively small works using the arc process at Niagara Falls, Ontario, and at Queenstown, each of which utilises 3,000 kw. producing 3,174 tons of 63 per cent. nitric acid per annum. A further plant of the same character was built at Vancouver in 1921, and is about to be enlarged, as it has been found possible to compete with Chile nitrate. Helium is obtained at Toronto and Calgary by McLennan's process. The production of cyanamide at Shawinigan in 1920 was 60,000 tons. The Shawinigan plant also manufactures synthetic acetic acid, acetone, etc., from calcium carbide, and is described in detail in *Engineering*, vol. xi., p. 220 (*Chem. Ztg.*, **1922,** 691, 964, 1143 ; **1923,** 95, 724, 824 ; *Chem. Ind.*, **1923,** 156, 321, 407 ; *Metallbörse*, **1923,** 695).

CHAPTER XIII

The Nitrogen and Allied Industries in the Remainder of America, excluding Chile

TOWARDS the end of the War the Cuban Air Reduction Company was erecting a plant at a cost of $100,000 for the production of oxygen at Havana, Cuba.

In **Mexico** there is a considerable dearth of fertilisers, particularly of potash for sugar and tobacco production, as the German imports of about 2,000 tons disappeared after 1914. The largest sulphuric acid works is that at Dinamita, Dgo., which utilises domestic sulphur and pyrites. A small quantity of nitric acid is produced from Chile nitrate. The Mexican chemical industry offers favourable prospects, as there are large deposits of bituminous coal, petroleum, sulphur, natural soda and sodium sulphate; and water power is also available.

Peru contains natural nitrate deposits, but the reports which appear periodically of very rich deposits of potassium nitrate have never been confirmed.

There are also small nitrate deposits in **Bolivia** and **Honduras,** the development of which has already been commenced.[1]

The Chilean nitrate industry has already been discussed in detail. Oxygen was at one time produced at Quilqué, and the Cia. Industrial "El Volcan" intended to erect a carbide works. In 1914 Chile imported 100 tons of anhydrous and aqueous ammonia.

In the **Argentine,** in 1920, four works produced 253,022 kg. of nitric acid per annum, four works produced 9,720 tons of sulphuric acid, two works produced 34,120 kg. of aqueous ammonia, and one works 8,673 kg. of anhydrous ammonia; one produced 15 tons of sodium cyanide, two works 15,200 kg. of calcium nitrate, and two other works 590,000 kg. of sodium nitrate; two works also manufactured 50 tons of ammonium chloride. In the Argentine, as in Chile, anhydrous ammonia is mainly used by the meat refrigerating plants, of which there were nine in 1915–16; a tenth was being erected, and three others were planned. In 1913, 560 tons of anhydrous ammonia were imported, of which half came from the United States, and only about 70 tons from Germany. The Argentine also imported

[1] *Chem. Ztg.*, 1920, p. 172.

about 67 tons of ammoniacal liquor. Many projects have recently been considered for developing the Iguazu Falls, 600 to 700 miles from Buenos Aires and Tucuman, the centre of the sugar district. The Iguazu Falls are on a tributary of the Parana in the Misiones Province ; the falls extend over a distance of 4 km., and the highest has a fall of 65 m. One hydro-electric plant is already working in the Argentine—namely, that of the Compania Hydro-Electrica de Tucuman, supplying 4,500 h.p. to the town of Tucuman and to the sugar works of the neighbourhood.

Brazil possesses ten large waterfalls, which are estimated to be able to supply 26,000,000 h.p. The smallest could supply 250,000 h.p. and more. Whilst the country does not contain as much petroleum as, for example, Mexico, it contains large deposits of " turfa," which is similar to oil shale. This is more especially found in the Camamu basin of the Province of Bahia. On distillation 1 ton of turfa is said to supply 306 litres of crude oil and 2·95 kg. of ammonium sulphate, compared with 99 litres of crude oil only from 1 ton of average Scotch shale. The only important oil wells in Brazil are in the State of Alagoas. The sodium nitrate deposits in the State of Pianhy are said to cover more than 600 sq. km. In some localities the crude nitrate contains as much as 80 per cent. of KNO_3. The deposits are connected by rail with the port of Camocim, beyond Ceara in North Brazil.

The Cia. Brazilia Carbureto de Calcio produced 61,000 drums of carbide in 1916. The Brazilian requirements for ammonia were supplied before the War by Germany, Great Britain, Belgium and Austria-Hungary. During the War practically all supplies were drawn from North America.

The Government of Uruguay negotiated a loan of $100,000 from a private bank and erected a Government sulphuric acid works at Capurro near Montevideo. The interest and sinking fund for this loan are administered by the Instituto de Quimica Industrial in Montevideo, which sold chemical products to the amount of $20,000 in 1916 and $70,000 in 1919.[1] A further $32,000 was expended on the erection of experimental plant for the manufacture of caustic soda, alcohol and ammonia. Nitric acid works for an output of 10 to 15 tons daily were also planned.[2]

Supplement, 1921–1924

In **Brazil,** nitrate is produced at Bahia which contains 75 per cent. KNO_3 when crude, and 99 per cent. when refined (*Chem. Ztg.*,

[1] *Zeitsch. f. angew. Chem.*, 1920, ii., 379.
[2] *Chem. Ind.*, 1921, p. 13.

1921, 1052). Brazilian coal has been quite successfully used for metallurgical purposes in Belgium (*Chem. Ztg.*, **1922**, 62). Modest beginnings of a nitrogen fertiliser industry have been made in the Argentine, Cuba, Jamaica, Mexico and British Columbia (*Chem. Ztg.*, **1922**, 62).

CHAPTER XIV

The Nitrogen Industry in Africa

HITHERTO this has been only very slightly developed, in spite of the fact that fertiliser requirements are considerable in many localities.

In 1919 the Canary Islands required, for the rapid recovery of their banana plantations, 3,500 tons of ammonium sulphate, 3,500 tons of calcium superphosphate, 1,500 tons of blood meal, and 3,500 tons of potash.

The Egyptian Power and Nitrogen Syndicate, Ltd., was formed in London in 1919 with a capital of £20,000 for the manufacture of fertilisers and carbide. Recently a pre-war project has been revived for the erection of an atmospheric nitric acid works at the Assuan Dam, in order to utilise the water power there available.

In 1916 the Committee of the South African Association of Electric Engineers proposed the establishment of an electro-chemical industry in South Africa, to manufacture calcium carbide, cyanamide, cyanide and other products. Cheap electric power, coal and limestone are available in the country. The demand for carbide is fairly important. The total imports of carbide in 1913 were 4,749 tons, and the gold mines alone utilised 4,500 to 5,000 tons in 1919. Of this quantity 3,000 tons were supplied by Canada, whilst 1,500 to 2,000 tons were manufactured by the mining companies at their carbide works which were erected during the War at Lainburg in the Transvaal. Severe competition is feared in the future from Australia, the carbide works in which country were expected to produce 80 to 100 tons of carbide daily in 1919-20. In 1918 carbide manufacture, to the amount of 2 to 3 tons per week, was started at Germiston, near Johannesburg. In 1919 the South African Carbide and By-Products Co., Ltd., was formed in London with a nominal capital of £307,500. The Chemico-Electric Company is the main shareholder in the enterprise; the Westminster Public Works Company, the Associated Portland Cement Manufacturers, White's South African Cement Company, the General Electric Company, and the Bingham Calcium Carbide Company are also interested. The works is being erected at an approximate cost of £252,200 at the

Ballengeich Colliery on the Durban-Johannesburg Railway. The proposed output of carbide is 4,186 tons per annum, and coal and oil-shale distillation by-products are also to be produced, such as tar oils, benzole, fuel oils, and so forth. The annual production of sulphate is estimated at 2,126 tons.

In 1918 the South African Ministry of Agriculture published the results of their researches on the fertiliser requirements of South Africa.[1] Good results were obtained with ammonium sulphate in Natal only, where this substance proved useful in conjunction with potash fertilisers and superphosphates for the cultivation of potatoes. In other portions of the country the crops did not increase, in accordance with expectations. The Ministry of Agriculture ascribed this partial failure with ammonium sulphate to the deficiency in lime of most South African soils, and also to the fact that the deficiency of nitrogen is not so great as elsewhere. It is expected that better results will be obtained with calcium cyanamide.

At Vrijheid a kind of anthracite is gasified in Mond producers. No tar is obtained, but only gas and ammonium sulphate, to the extent of 250 to 350 tons per month. With the exception of a small portion, used for heating the boilers, the gas is at present allowed to escape unburnt into the air. Attempts to manufacture sulphuric acid from the pyrites of the Rand have not proved very successful. Proposals to develop by-product coking in the Natal district on a large scale only assumed a more concrete form in 1919.[2] The Tweefontein Colliery intend to produce by-products from their lower-grade coal.[3] They do not propose to use coke ovens, but the Lymn-Rambush producer, an improved form of Mond producer, which converts the coal completely into gas and ammonium sulphate, together with a small quantity of other products. Since 1918 a Johannesburg firm has produced liquid ammonia to supply the home demand of South Africa. The coal production of Natal in 1905 was only 1,148,000 tons.

The South African Nitrate and Potash Corporation was founded in 1919 with a capital of £160,000, which is later to be increased to £500,000, to develop the natural nitrate deposits near the Asbestos Mountains between Prieska and Griquatown, which are said to be quite considerable.[4] They yield potassium nitrate.

The phosphate rock at Saldanha Bay is being exploited by the

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 307.
[2] *Ibid.*, 1919, ii., 534.
[3] *Ibid.*, 1920, ii., 87.
[4] *Ibid.*, 1919, ii., 362, 431.

Salphos Fertiliser Company for the production of fertilisers by the Tromp process.[1]

The Victoria Falls and Transvaal Power Co., Ltd., will be of importance in the future as a supplier of electricity.

The production of coke and carbide is practically confined to British South Africa.

[1] *Chem. Ztg.*, 1920, p. 172.

CHAPTER XV

The Nitrogen Industry in Asia

THIS industry is at present only at the beginning of its development, which has so far been practically confined to Japan.

Before the War the manufacture of fertilisers in Japan was relatively unimportant, and was mainly concerned with the treatment of crude phosphates. Small quantities of ammonium sulphate and cyanamide were also manufactured. The imports of fertilisers were, on the other hand, fairly important. The main imports were organic feeding stuffs and fertilisers, such as bone cake, linseed cake, cotton-seed cake, rice bran, bone meal, fish-oil cake, and so forth, which were obtained from Manchuria, China, Corea and elsewhere. The main source of nitrogen is human fæces, which supply a nitrogen content of about 260,000 tons. The import of ammonium sulphate was maintained during the War at an average of 80,000 to 110,000 tons, which was almost exclusively purchased from England. After the commencement of the War the imports gradually ceased, particularly as exports from England were prohibited. Japan had therefore, on the one hand, to increase its utilisation of organic fertilisers, but, on the other hand, it commenced to establish a nitrogen industry. The manufacture of ammonium sulphate in particular was considerably developed. In 1915 31,855 tons were manufactured, and in 1918 the output capacity rose to about 70,000 tons. As the internal consumption of ammonium sulphate was at least 80,000 to 120,000 tons per annum, a deficit of about 50,000 tons had to be covered by imports. The price of ammonium sulphate rose until the autumn of 1919 and then declined. One pikul (about 60 kg.) cost 8·1 yen (16*s.* 10*d.*) just before the War. In March, 1917, it cost 13·5 yen (£1 8*s.* 3*d.*) ; in the autumn of 1919, 31·8 yen (£3 6*s.* 6*d.*). The production of calcium cyanamide is stated to average 3,000 tons per annum, according to which figure the works at Osaka and Hokkaido, if fully occupied, must have converted a considerable quantity of calcium cyanamide into ammonium sulphate. The imports of Chile nitrate were 26,726 tons in 1913, and 24,425 tons in 1914 ; the value of the imports of this material was £645,000 in 1916, £1,015,000 in 1917, and £1,180,000 in 1918. Before the War Japan used about 30,000 tons of Chile nitrate per annum, but pur-

chased 200,000 tons in 1920, in order to have a sufficient reserve for agricultural and industrial purposes. In 1917 a ton of nitrate in Japan cost 194 yen (£20 5*s*.), compared with 117 yen (£12 4*s*. 6*d*.) in 1913.

The Japanese Ministry of Agriculture published certain statistical data in 1918, which, however, only extend to the end of 1916.[1] At the end of 1916 there were 24,335 manufacturers of fertilisers and 45,470 dealers. The total production had at that time a value of £6,325,000, which was distributed as follows :—

	£
Mixed fertilisers	1,348,000
Animal fertilisers	943,000
Vegetable fertilisers	1,965,000
Mineral fertilisers	2,069,000
Total	£6,325,000

The imports of fertilisers were valued at £3,550,000 in 1916 and £8,150,000 in 1917. The exports of fertilisers were considerably reduced in April, 1915, and still further in September, 1917, on account of the internal scarcity; they had a value of £420,000 in 1916 and £210,000 in 1917. The eleven largest fertiliser companies in Japan produced or sold the following quantities of superphosphate and other products :—

		Tons.
In 1916	about	452,000
In 1917	,,	610,000
In 1918	,,	611,000
First half of 1919	,,	460,000

At the commencement of 1920 business became extraordinarily active on the Japanese fertiliser market, as the purchasing power of the consumers was so increased by the increased prices for rice and other foodstuffs that the quite considerable increase in the price of fertilisers could not for a time restrict the demand. The speculative activities of the dealers, who expected still greater price increases, led, however, to such large imports that at the end of the first quarter of 1920 the fertiliser market in Japan was absolutely overstocked. During this period fertilisers were imported to the value of about 85,000,000 yen (about £8,885,000) more than in the first quarter of 1919, or almost as much as in the whole of 1913. From January to March, 1920, the imports of Chile nitrate amounted to 8,000,000 yen (£835,000); of bean cake, 48,000,000 yen (£5,015,000); phosphates, 4,000,000 yen (£420,000); and ammonium sulphate, 11,000,000 yen (£1,600,000). The speculators were disappointed in their hopes of

[1] *Zeitsch. f. angew. Chem.*, 1918, iii., 534.

large profits through the sale of these large stocks, as the economic crisis which ensued in the interval, and the flooding of the market, led to a sudden drop in prices.[1]

To avoid over-production and underselling, the Osaka Kasuka Hiryo Company and the Nippon Seimi Seizo Company, which both manufacture superphosphates, combined to form a new company, the Nippon Kasaki Hiryo Company.[2] The new company is supplied with pyrites and phosphates by the Seikoku Ryusan Hiryo Company, which was founded at the same time.

The alkali and caustic soda industry of Japan was carried out before the War in two works, with an annual output of 5,000 tons of alkali; in 1919 there were twenty works with a production of 150,000 tons. The condition of the alkali industry in 1919 was stated to be bad, in consequence of the decline in prices of the finished products and advances in the prices of salt and coal.[3]

The coal production of Japan was 30·3 million tons in 1919;[4] a further 1·1 million tons were imported and 1·7 million tons exported. The industrial requirements of coal were 15·5 million tons. Coke manufacture played a relatively unimportant part until a few years ago; originally it was almost exclusively carried out in beehive ovens.[5] The first modern plant, of 21 Solvay ovens, was built by the Osaka Semi Kogyo Kabushiki Kaisha, of Osaka, which erected 20 further ovens in 1914. The Government steel works at Yawatamachi commenced to manufacture by-product coke in 150 Solvay ovens in 1907-8. Coal dust is utilised in 90 Koppers ovens at Omuta and in a Mond gas plant at the Tagawa Colliery. The Mitsuibishi Goshi Kaisha is operating 25 Solvay ovens at Tobota, and made plans in 1914 for the construction of a by-product plant in Corea near Kenjiho, north of Seoul, using ovens of German type. About that time the colliery proprietor, Aso, intended to erect 25 Solvay ovens, and the South Manchurian Railway Company intended to establish a Mond gas and gas-engine plant at the Fushun coal mine. The firm of Mitsui established a school for gas technology at Omuta before the War, which was attended by 200 pupils in 1913-14. The development which had thus been prepared led to a large expansion of the coke oven by-product and ammonium sulphate industry during the War, as has already been indicated.

British exports of ammonium sulphate to Japan amounted to

[1] *Chem. Ztg.*, 1918, III., 534.
[2] *Zeitsch. f. angew. Chem.*, 1920, ii., 284.
[3] *Ibid.*, 1919, ii., 570.
[4] *Chem. Ztg.*, 1920, p. 547.
[5] *Ibid.*, p. 40.

108,238 tons in 1913 and 107,795 tons in 1914. The Japanese home production, or output capacity, increased from 20,000 to 30,000 tons in 1915, to 50,000 tons in 1917, 70,000 tons in 1918, 83,000 tons in 1919, and 113,000 tons in 1920. The imports in 1919 were about 50,000 tons.[1] The Japanese works are making great efforts to improve the somewhat poor quality of their product, in order to prevent competition from imported material. There were 120 gas-works in Japan in 1919, most of which recover their by-products.

If the above-mentioned maximum output figures are really attained, the Japanese market should be self-supporting in a comparatively short time. The fact that the import of considerable quantities is still relied on and that the German product is still sought for[2] shows how promising the development of Japanese agriculture is held to be, and also indicates the anticipation of re-exports into Corea and Manchuria. The great exertions which are continually made to develop Japanese agriculture by extensive Government support have as an object to render Japan independent of foreign countries with regard to food supplies and certain raw materials, such as sugar beet, cattle food, and so on.[3]

A part of the ammonium sulphate production comes from the calcium cyanamide works. The Nippon Tisso Hiryo Kabushiki Kaisha, of Osaka (a limited company for the supply of nitrogenous fertilisers), operates the Frank-Caro process, and had in 1912–13 an annual output capacity of 12,000 tons of calcium cyanamide. Apart from this company, the Japanese Electro-Chemical Company, of Tokio, manufactured cyanamide in Hokkaido. For some time the conversion into ammonium sulphate proved so profitable that the money spent in initial experiments and in failures was very fully recovered. It was reported in 1918 that three new cyanamide works were either in course of erection or planned, for example, near Fukui. The Electro-Chemical Company, of Tokio, erected a carbide works at Fushun in 1918, which was to produce not only calcium cyanamide, but also ammonium sulphate.[4] The same firm intends to erect cyanamide and ammonium sulphate works in Manchuria.

The large demand for ammonium sulphate, both internally and abroad, for example, in Java, India, etc., enabled these works to produce profitably. In order to lower domestic prices, a threat to prohibit the export of ammonium sulphate was made at the commencement of 1918. The consequence was that the works preferred not to nitrogenate their carbide, but to export it as such. The price

[1] *Chem. Ztg.*, 1920, p. 171.
[2] *Zeitsch. f. angew. Chem.*, 1919, ii., 735.
[3] *Chem. Ztg.*, 1920, p. 48.
[4] *Ibid.*, p. 479.

was 380 yen (£39 14*s*.) per ton. Before the War almost the whole of the carbide used in Japan was imported. In 1917, however, there were already fifteen carbide works with an annual production of 26,489 tons ; in 1918 the output capacity rose to about 32,000 tons. Although but little carbide was exported in 1915, almost 2,100 tons were exported between January 1st and the end of November, 1917. The American imports have practically ceased. The export figures are as follows :—

	Kin.[1]		Value.
1915	752,000	..	48,200 yen
1916	2,102,000	..	263,300 ,,
1917	5,442,000	..	853,800 ,,
1918	21,633,500	..	5,476,000 ,,
1919	2,549,900	..	525,200 ,,
1920 (to February) . .	336,600	..	66,100 ,,

The first Japanese carbide works was at Koriyama, and was started in 1901 with a normal production of 50 to 60 tons monthly. The manufacture was later undertaken by a second works at Sendai and a third at Nagaoka, but the production remained small, so that the main requirements have to be covered by imports. Before the War the market was controlled by a syndicate, but after the War had commenced the development of a powerful domestic carbide industry was more rapid. A number of power stations erected carbide furnaces in order to utilise their off-peak load. This development proved so satisfactory that many plants were under construction in 1918.[2] The cement works also turned to carbide manufacture. Before the War the production costs of 100 kg. of carbide in Japan were 13*s*. to 15*s*.; in 1918 they had risen to 20*s*. to 21*s*. Before the War carbide was sold at 16*s*. to 20*s*. per ton, whilst in 1918 it cost about £3 for inland consumption, and £3 19*s*. to £4 for export. The main exports are to Australia, the Philippines, Java and India. The product is often inferior, containing 55 to 67 per cent. of pure carbide, whilst it has to compete on the open market with an 80 to 85 per cent. carbide.

The development of water power in Japan is relatively slow. In 1919 the Taisho Suiryoku Denki Kaisha (Taisho Hydro-Electric Company) obtained a concession for a power station of 16,000 h.p. at the source of the Totsugawa. The available capital was 10,000,000 yen (£1,045,000). The power station is about 220 miles distant from Kobé. The firm of Suzuki & Co. was erecting new ironworks in Oita, Kyushu, in 1919, in which it was proposed to instal the first electric

[1] 1 kin is equal to 0·6 kg.
[2] *Chem. Ztg.*, 1918, p. 472.

blast furnaces in Japan. The plant is intended to cover 14,175 sq. m., and hydraulically produced electricity will be used. There is a new project by an American aluminium company which intends to form a new company, of which one-half of the capital is to be Japanese,[1] in order to acquire from the Government the water-power rights in the prefecture of Toyama.

In the summer of 1918 the Japanese Parliament granted a sum of 263,000 yen (£27,500) for carrying out experimental work on the nitrogen industry and more particularly on the atmospheric nitric acid industry. The Government built a research laboratory at Sugamo, near Tokio, which commenced work in the spring of 1919. The arc process has not yet been worked in Japan, nor has the catalytic oxidation of ammonia been seriously undertaken. On the other hand, J. Takamine acquired in 1918 the working rights for Japan of the synthetic process of the American Chemical Company in order to erect a works utilising this process. As is well known, the process did not prove successful, and therefore no Japanese company was formed. According to American information,[2] a company was formed under the direction of Takamine in 1919, with a capital of 20,000,000 yen (£2,000,000), to operate the process in which both American and Japanese financiers are interested. Meanwhile Japanese interests approached the B.A.S.F. with a view to introducing the Haber-Bosch process into Japan. It is also intended to hold a large exhibition of pharmaceutical and chemical products in Japan in March, 1921. A company has been formed in Kobe for working the Claude process.

The Société d'Oxygène et d'Acetylène du Japon increased their capital in 1918 from 800,000 to 2,000,000 fr. The Japanese firm of Okura [3] is considering the erection of a large fertiliser works at Wiju in Northern Corea, with a capital of 3,000,000 yen (£300,000). Bean cake and bean oil are to be manufactured.

The import duties on dyestuffs and chemical products are to be considerably increased, in order to protect the home industry.[4] Hopes were entertained of exporting nitrogenous fertilisers in the future to South Africa, India, Java and other countries with the help of cheap electric power. The alkali industry still exists, in spite of severe competition from England and America. The Japanese import statistics show increased figures for sodium cyanide, ammonium carbonate, ammonium chloride, and so on.[5]

[1] *Chem. Ztg.*, 1920, p. 24.
[2] *Zeitsch. f. angew. Chem.*, 1920, ii., 92.
[3] *Chem. Ztg.*, 1920, p. 143.
[4] *Metallbörse*, 1920, p. 1280.
[5] *Zeitsch. f. angew. Chem.*, 1920, ii., 248.